Investigation of Ways to Make Toy Projectiles Fly Farther, Straighter, and Safer by Adopting Memory Foam

by

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B.S. Materials Science and Engineering
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Sunyoung Kim

Submitted to the Department of Materials Science and Engineering on May 22th, 2009 in partial fulfillment of the requirements for the degree of Master of Science in Material Science and Engineering

Abstract

The purpose of this research has been to improve the performances of toy projectiles by modifying their design. While the developed product is required to comply with all applicable safety specifications and regulations, it is also required to satisfy customers. Through brainstorming, over 30 designs of projectile were generated, 10 models distilled from brainstorming models were prototyped and evaluated through the performance tests.

The performance tests involve distance evaluation, accuracy evaluation, safety evaluation, and supplementary evaluation. The distance evaluation is for verifying the performance of flying farther. This test measures flying distance, and initial velocity through high speed imaging, and calculates distance per kinetic energy, and drag coefficient. The accuracy evaluation indicates how accurately the each projectile model is able to fly to the aim, and it is performed by calculating the variance of the lengths between the center of the dart board and the marks which projectiles made when they bumped into the dart board. The safety evaluation is for confirming the compliance of developed models with the safety standard and it achieved with calculating the kinetic energy density. The supplementary evaluation is for comparing the production error and performing error.

Through the analysis of performance tests' results, the models were modified and refined from the best performance model. The refined models were prototyped and evaluated through the performance tests as well. The refined model #13-1 has the same range of flight and 37.69% better accuracy than the state-of-the-art projectiles, and the refined model #13-3 has the 31.78% longer range of flight and comparable accuracy to the state-of-the-art projectiles.

In conclusion, the final model was attained with specific concepts: The surface of the projectile should be smooth without bump between head and body; Two things should be avoided: too high mass because it limits the distance of flight and generates high kinetic energy density, and too low mass because it causes unsatisfied accuracy; The uniform density distribution is desired for straightness of flight; The head of the projectile should be close to streamline; The contact area should be composed with soft material that would be memory foam to protect users from injury; Stiff material not deformed by air pressure should be installed in the head and the shape of the stiff material should not sharp; The occupancy of stiff material's volume in the head should not exceed 25% of the whole volume of the head.

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Chapter1

Introduction

1.1 Problem Statement

As toys are ubiquitous in the realm of children who have the propensity to chase amusement and be vulnerable, they are mandated to be safe and enjoyable. It has been the ultimate purpose of this research to fabricate projectile toys much safer and more amusing. While the modified or developed product is required to comply with all applicable safety specifications and regulations which have been provided by the company, Hasbro, Inc., it is required to satisfy customers who are often complaining about the distance of the flight.

1.1.1 Objective 1

During designing and modifying projectiles as toys, the primary thing which should be carefully considered is safety. The possibility of wounds must be reduced through deliberation of the requirement for safety throughout the process of design and modification. The main users of Nerf® guns and darts are children age between 6 and 12, and the toys are even played as 'war,' which means darts can be shot against children, so the toys are mandated to minimize any potential for injury especially eye and face injury. In addition, according to a common custom, children would not be confident of reading written safety warnings, or anticipated to thoroughly understand the risks, resulted in not following these warnings. Therefore, it is indispensable for the designer to fabricate the products with higher standards of safety.

1.1.2 Objective 2

While customers play with Nerf® guns and darts, they expect the darts fly far, and some of them do not satisfy with the range of flying darts in market. This problem is proven by that the most complains of customers are about the range of flying darts. The longest range is up to 35 feet for N-STRIKE LONGSHOT CS-6™, one of the guns for longest range, but numerous customers complain about their experiences of less range of flight. Moreover, the customers feel even the longest range is not enough and go as far as to modify their guns. It is certain that these untested modifications are risky to injure the players. Therefore, acquiring longer range should be the objective of this research to satisfying customers, and it is important that a careful balance between safety and the performance. It is required to fabricate the products fly farther with less energy.

1.1.3 Objective 3

The toys are frequently played with dart boards which require higher accuracy and/or straightness for flying projectiles. In addition, as a matter of safety, higher accuracy is seriously desirable factor. The flight along the unexpected direction has more possibility to injury players.

1.2 Contribution of Thesis

Among over 30 kinds of developed designs of projectile through brainstorming, 10 kinds of models including 8 developed projectile models and 2 state-of-the-art projectile models were selected as initial investigation models. These models were prototyped and verified through several tests. Evaluation tests for distance of flight: measuring distance, measuring initial velocity through high speed imaging, calculating distance per kinetic energy, and computing drag coefficient; evaluation test for accuracy; and evaluation test for safety by calculating kinetic energy density were performed to get data of each projectile's performance. Through these 10 kinds of models' performance evaluation, the specifications, such as streamlined shape, smooth surface, uniform density distribution, and proper mass, which have promising potential to provide the better performances, were realized. The model #7 shown in Figure 1-1, replaced the head with memory foam ear plug, which has the unsatisfied accuracy, but the best performance of farther flying, was chosen as the basis model for the modification step. Then, the modification step was concentrated on improving the performance of accurate flying.

Figure 1-1 Model #7

Through the modification on the model#7: applying pin inside of memory foam head to prevent the deformation involving bending because of the influence of air pressure; installing washer for higher mass, the higher and satisfied accuracy was acquired without demolishing previously attained performance of farther flying. As a result of the modification on model #7, the model which has the same range of flight and higher accuracy and/or the model which has farther range of flight and the same accuracy could be attained.

After all the evaluation tests, and analyzing the result of the tests with initial developed models and modified models, the final scenario could be contrived as seen in Table 1-1 and the final model could be suggested as seen in Figure 1-2.

Scenario	Model	Distance	Accuracy	Safety
①	#7	Over 29.66% farther than the standard darts	Worse than the standard darts	Safest among the scenarios
②	#13-1	As far as the standard dart	37.69% better than the standard darts	2^{nd} safest among the scenarios
③	#13-3	Over 31.78% farther than the standard darts	Similar to the standard darts	Just under the limit
④	#7 estimated with the limit kinetic energy density	Over 45.23% farther than the standard darts	Worse than the standard darts	The limit

Table 1-1 Summary of Final Scenarios

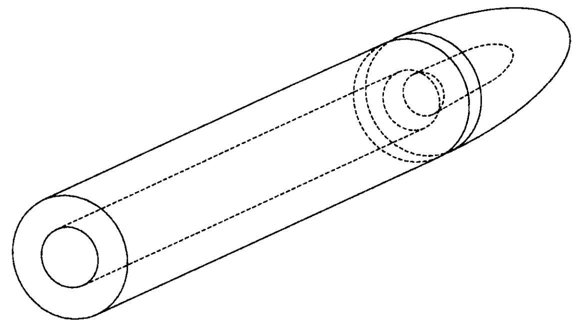


Figure 1-2 The Final Projectile Model

1.3 Roadmap to Thesis

Throughout the development and investigation of projectiles for attaining better performances, the basic Aerodynamics mainly from the text Introduction to Flight by Anderson [1] was considered sufficiently. On the other hand, a standard structured method of product design similar to those presented in the M.I.T Product Design Course 2.744 and the text Product Design Development by Ulrich and Eppinger [2] and was adopted for this thesis.

There are six chapters in this paper: Introduction, Background, Methodology of Evaluation, Concept Development Procedure, Result and Analysis, and Conclusion. The Introduction phase involves the three objectives of the research and the contribution and the roadmap of the paper. The Background section contains the necessary knowledge and information for the actual product development and modification process. It presents the safety standards of darts, aerodynamic and fluid dynamic background for developing darts design, and properties of materials including memory foam, rubber, and cork which compose darts. The Methodology of Evaluation section describes the method used for evaluation test and calculation to verify whether each projectile model serves the object of research or not. The Concept Development Procedure section details the standard phases of product development: Searches, Brainstorming, Concept Sketch, Prototyping, Evaluation Test, and Result Analysis. The Result and Analysis section discusses the results of evaluation tests of projectile models to approach the conclusion and the pertinent reasons causing that results are explained specifically. The Conclusion section suggests the final model and future work.

Chapter 2

Background

The background chapter contains the necessary knowledge and information for the actual product development and modification process. This phase involves the safety standards of darts, aerodynamic and fluid dynamic background for developing darts design, and properties of memory foam which compose the developed projectiles. These steps enable the designer to become familiar with the subject, stay focused on feasible ideas, and finally determine the direction of the research.

2.1 Safety Standard

The safety factor, one of the objectives, generates the research to concentrate on achieving higher level of safety. On the other hand, the standard level of safety which is mandated to comply without exception, no matter how excellent the performance of dart is, exists to protect the player from the injury. The sponsor company, Hasbro, Inc. provided a detailed listing of all of these safety specifications for projectiles in a document entitled, "Corporate Quality Assurance, Safety and Reliability Specification, SRS-045, Projectiles" [3]. This document presents specifications for the various structural characteristics and kinetic parameters of projectiles used on Hasbro, Inc. products. The full document can be found in Appendix A, and the following are succinct summaries of the applicable safety and reliability specifications provided by Hasbro, Inc. which have influenced the design and modification process of darts.

TEST PROCEDURE

Kinetic Energy Determination

The kinetic energy (in joules, J) of a projectile shall be determined from the following equation:

$$\text{Kinetic energy} = \frac{1}{2}mv^2$$

m = mass of projectile (Kg)

v = velocity of the projectile (meter/second)

The mass of projectile shall be determined by weighting a sample on a laboratory balance. A sufficient sample size (at least 30) of projectiles shall be weighted to determine the average weight plus 3 standard deviations. The velocity of a projectile shall be determined by firing a sample from the discharge mechanism of the toy projected out in front of the radar gun.

Impact Test for Projectiles

Projectiles shall be propelled by their discharge mechanism six times into a concrete block wall (or equivalent surface) located at a distance 1 foot plus the length of the projectile from the front end of the discharge mechanism. The discharge mechanism shall be aimed perpendicular to the wall.

Improvised Projectile Test

Determine through experimentation if discharge mechanism is capable of discharging projectiles other than the projectile specifically designed for use with the discharge mechanism. Testing of improvised projectiles shall include correction pen cap, marker, marker cap, paper clip, pen, etc.

Projectile Configuration Evaluation

Projectiles must not have projections (i.e. ribs, missiles, fins, etc.) that protrude from the main body of the projectile and have the potential to generate a "fishhook" effect. Generally, projections that extend 3/16" or more from the body of the projectile and subtend an angle of 30 – 90 degrees from the body and are not "blended" to the body will be considered as having the potential to generate a "fishhook" effect and are not acceptable for use on the Hasbro, Inc., products.

Projectile Kinetic Energy Density

The projectile kinetic energy density must be determined on all projectiles with a kinetic energy greater than 0.08J. The projectile kinetic energy density is the kinetic energy of the projectile divided by its contact area. The kinetic energy density is expressed as joules/area.

SPECIFICATIONS

- Projectiles must not have sharp edges per SRS-003, sharp points per SRS-002, or parts that fit without compression into the Hasbro® cylinder per SRS-001.
- The projectile tip means any portion of a projectile that can reasonably be expected to contact an impact surface (e.g. an eye) during flight. The possible tip is not only a tip end or leading edge of a projectile, but also the edge of the disc on disc or saucer like projectiles.

  Projectile must have a tip radius greater than 2 mm (.08 in.). The minimum allowable tip radius increases in direct proportion to the kinetic energy of the projectile per the table below:

Projectile Energy Level	**Minimum Allowable Tip Radius**
~.025 J	2 mm
.025 J ~ .05 J	3 mm
.05 J ~ .10 J	4 mm
.10 J ~ .15 J	5 mm
.15 J ~ .20 J	6 mm

Table 2-1 Allowable Tip Radius According to Projectile Energy Level

Projectiles in the form of arrows or darts or other missile-shaped objects that are intended to be thrown by the user must have resilient tips with an impact area of at least $4cm^2$.

- Any projectile fired from the toy that has a kinetic energy that exceeds .08 J shall have an impact surface of a resilient material
- A protective tip shall not be detached from the projectile when subjected to torque/tension test per SRS-006 (i.e. 8 in-lbs torque/20.5 lbs tension) and shall not detach or produce or reveal hazardous points or edges when fired into a solid object according to test procedure.
- The kinetic energy density of projectiles must not exceed 1600 J/m^2.

2.2 Flight

The projectiles fly in air by triggering force of toy guns. When projectiles fly, the only force which affects to the projectiles is gravity and drag. Because it is indoor play, the other effect including wind can be ignored. The definitions of drag and drag coefficient are basically from National Aeronautics and Space Administration. [4][5]

2.2.1 Drag

Simply speaking, drag, which is called air resistance or fluid resistance, is a force. Drag refers to the forces that oppose the motion of an object through a fluid or the motion of flowing fluid containing a stationary object. For example, when one holds a wood plate vertically to the water flow in the river, the one feels the force, that wood plate is pushed out by the water flow. In addition to, when one walks in the heavy wind and rain holding tilted umbrella to avoid rain, the one feels the force that is pushed by wind. In the above cases, the forces which are felt by people's hands are drag. Drag forces depend on the velocity, unlike other resistive forces such as friction, are independent of velocity, and act in a direction opposite to the instantaneous velocity.

Drag can be divided into several types: parasitic drag, lift induced drag, and wave drag. The drag from the source of aerodynamic resistance to the motion of the object through the fluid depends on the shape of the aircraft and is called parasitic drag including foam drag, skin friction drag, and interference drag. As air flows around a body, the local velocity and pressure are changed. Since pressure is a measure of the momentum of the gas molecules and a change in momentum creates a force, a varying pressure distribution will create a force on the body. The magnitude of the force can be decided by amalgamating the local pressure times the surface area around the entire body. The constituent of the aerodynamic force that is opposed to the motion is the drag; the constituent perpendicular to the motion is the lift. Both the lift and drag force operate through the center of pressure of the object. This is a foam drag. Drag due to surface roughness is skin friction drag. Additionally, the presence of multiple bodies in relative proximity may incur interference drag.

There is an additional drag component caused by the production of lift. Aerodynamicists have named this component the induced drag. This drag occurs because the flow near the wing tips is distorted span wise as a result of the pressure difference from the top to the bottom of the wing. Swirling vortices are formed at the wing tips, which produce a down wash of air behind the wing which is very strong near the wing tips and decreases toward the wing root. The local angle of attack of the wing is increased by the induced flow of the down wash, giving an additional, downstream-facing, component to the aerodynamic force acting over the entire wing. This additional force is called induced drag because it has been "induced" by the action of the tip vortices. It is also called "drag due to lift" because it only occurs on finite, lifting wings. The magnitude of induced drag depends on the amount of lift being generated by the wing and on the wing geometry. Long, thin (chord wise) wings have low induced drag; short wings with a large chord have high induced drag.

Additional sources of drag include wave drag and ram drag. As an aircraft approaches the speed of sound, shock waves are generated along the surface. There is an extra drag penalty called wave drag that is related with the formation of the shock waves. The magnitude of the wave drag depends on the Mach number of the flow. Ram drag is associated with slowing down the free stream air as air is brought inside the aircraft. Jet engines and cooling inlets on the aircraft are sources of ram drag. [4]

To make the definition clearly by functions, at very low speeds for small particles, drag is approximately proportional to velocity and can be expressed in the form.

$$F_d = -bv \tag{2.1}$$

The negative sign implies that it is always directly opposite the velocity.

For higher velocities and larger objects the drag is approximately proportional to the square of the velocity.

$$F_d = -\frac{1}{2} c_d \rho A v^2 \tag{2.2}$$

ρ is a density of air, A is the reference area that is the cross-sectional area, and $c_d$is a numerical drag coefficient.

Drag is the first thing to be considered in the design of objects which are moving in the air or water such as aircraft, submarine, and car, because it is necessary to reduce air drag for making objects run farther with the same amount of energy. When designing of foam Nerf® darts which fly in the air, the drag, phenomenon of the fluid dynamics is a point to be seriously considered. Designing streamline shape following the shape of fish and the making surface have the property of scales are to reduce drag coefficient.

2.2.2 Drag Coefficient

The drag coefficient is a number which aerodynamicists use to model all of the complex dependencies of drag on shape, inclination, and some flow conditions.

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A} \tag{2.3}$$

The drag coefficient then expresses the ratio of the drag force to the force produced by the dynamic pressure times the area. This equation gives a way to determine a value for the drag coefficient. In a controlled environment (wind tunnel) the velocity, density, and area can be set and the produced drag are measured. The choice of reference area (wing area, frontal area, surface area, etc.) will affect the actual numerical value of the drag coefficient that is calculated. When reporting drag coefficient values, it is important to identify the reference area that is used to determine the coefficient. The drag can be predicted that will be produced under a different set of velocity, density (altitude), and area conditions using the drag equation.

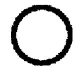
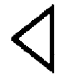
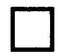
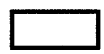
Shape		Drag Coefficient
Sphere		0.47
Half sphere		0.42
Cone		0.50
Cube		1.05
Angled Cube		0.80
Long Cylinder		0.82
Short Cylinder		1.15
Streamlined Body		0.04
Streamlined Half-body		0.09

Table 2-2 Measured Drag Coefficient according to the shape [6]

The drag coefficient contains not only the complex dependencies of object shape and inclination, but also the effects of air viscosity and compressibility. To appropriately use the drag coefficient, it should be confirmed that the viscosity and compressibility effects are the same between the measured case and the predicted case. Otherwise, the prediction will be erroneous. For very low speeds (< 200 mph) the compressibility effects are negligible. At higher speeds, it becomes important to match Mach numbers between the two cases. Mach number is the ratio of the velocity to the speed of sound. At supersonic speeds, shock waves will be present in the flow field and the wave drag must be accounted for in the drag coefficient. So it is completely incorrect to measure a drag coefficient at some low speed (say 200 mph) and apply that drag coefficient at twice the speed of sound (approximately 1,400 mph, Mach = 2.0). It is even more essential to equal air viscosity effects. The important matching parameter for viscosity is the Reynolds number that states the ratio of inertial forces to viscous forces. In the discussions on the sources of drag, it should be recalled that skin friction drag depends directly on the viscous interaction of the object and the flow. If the Reynolds number of the experiment and flight are close, then we properly model the effects of the viscous forces relative to the inertial forces. If they are very different, we do not correctly model the physics of the real problem and will predict an incorrect drag. [5]

2.3 Material

Memory foam is installed for developed projectiles as its low mass, and safety in spite of easy deformation. Memory foam has lower mass than the rubber which is used for the head of state-of-the-art projectiles, and softer, so safer, than the rubber material.

2.3.1 Memory Foam

Shape-memory polymers are a rising division of polymers with a variety of applications straddling every life. Such applications can be found in, for example, smart fabrics, heatshrinkable tubes for electronics or films for packaging, selfdeployable sun sails in spacecraft, self-disassembling mobile phones, intelligent medical devices, or implants for minimally invasive surgery. These examples cover only a small number of the possible applications of shape-memory technology, which shows potential in numerous other applications. The elemental aspects of the shape-memory effect are offered at the following. Shape-memory polymers are dual-shape materials belonging to the group of 'actively moving' polymers. They can actively transform from a shape A to a shape B. Shape A is a temporary shape that is attained by mechanical deformation and consequent fixation of that deformation. This process also determines the alteration of shape shift, resulting in shape B, which is the permanent shape. In shape-memory polymers reported so far, heat or light has been used as the stimulus. Using irradiation with infrared light, application of electric fields, alternating magnetic fields, or immersion in water, indirect actuation of the shape memory effect has also been realized. The shape-memory effect only relies on the molecular architecture and does not require a specific chemical structure in the repeating units. Therefore, intrinsic material properties, e.g. mechanical properties, can be adjusted to the need of specific applications by variation of molecular parameters, such as the type of monomer or the comonomer ratio. [7]

Chapter 3

Methodology of Evaluation

This phase involves the methodology of evaluations for verifying projectile models' performances which are distance, accuracy, and safety. This chapter explains how to verify whether each projectile model serves the object of research or not. The description and procedure of measurement and/or calculation for evaluating each projectile model are specifically provided.

3.1 Distance of Flight Evaluation

Evaluation for the performance of farther flying were performed by several parts, such as distance measurement, initial velocity measurement, distance per kinetic energy calculation, and drag coefficient calculation. Not measuring just distance, but measuring diverse items which are related to distance should improve the reliability of data. Following are the explanation of each test.

3.1.1 Distance Test

Description

The distance or the range of flight means the maximum distance of flying projectile before it reaches the ground.

Procedure

To comply with the test description of Hasbro, Inc., projectiles were shot at 1.2m (40 inch) height indoors with the gun which is mounted 35° to the ground. The experiential test for measuring of distance of flight is performed inside not to be influenced by wind, and it is significant to construct firm mounting because the angle of the gun to shot affect to the distance considerably. 12 times for each model are shot, and the average of 10 times, except for longest and shortest distances, is considered as the distance of each projectile model.

3.1.2 Initial Velocity and Average Velocity Test

Description

The initial velocity means the velocity of the projectile models just after getting out of the Nerf® toy gun. Higher velocity of the projectile model represents that it transfers the potential energy of the Nerf® toy gun (or the triggering force) into the kinetic energy of projectiles well. In addition, it is certain that projectile model which has higher initial velocity flies farther.

The average velocity means the average velocity of the projectiles during the flight. The initial velocity should decrease because of drag. This average velocity is used for calculating kinetic energy density for safety test.

Procedure

5 pieces of high speed imaging for each projectile model were taken through the procedure which is explained at the following. After that, the initial velocity, average velocity and trajectory of each projectile model could be achieved by analyzing the high speed image files through the software "Proanalyst®."

High Speed Imaging

It is unmanageable to take a photograph or video of swiftly moving objects by a general camera which people are using to take characters or landscapes, so high speed camera is introduced for taking a photograph or video of proceeding objects such as shot missiles, thrown balls, or falling water drops. 'Nemview®' is software for observing and processing directly with high speed camera. The process of taking high speed videos with the camera and the software will be explained at the following.

First, the appropriate camera should be determined according to which video is required. There are several kinds of high speed camera with different specifications such as, Redlake MASD PCI Motionscope, which is for monochrome high speed imaging at a speed of up to 8,000 images per second; Redlake MASD Ektapro 1012, which is for monochrome high speed imaging at a speed of up to 12,000 images per second; and NAC model, which is for color high speed imaging.

Then, the suitable lens for the camera is selected according to which high speed imaging is demanded to be taken. Taking a narrow area needs longer focal length and taking broad area needs shorter focal length. The focal length is transcribed on the frame of lens.

After camera, lens, and computer are prepared, they need to be set up. For setting those up, tripod is established firmly on the ground, and the camera is mounted on the tripod. The lens is adapted to the camera and the connection with USB cable between camera and computer is constructed stably. If needed, the lamps are appended to this setup.

Following that, the camera focusing to the object is turned on, and the computer is turned on. When the 'Nemview®' icon is double clicked, the program is commenced while window is opened. On the top of the window, click 'camera' and 'open camera.' Then the live scene which the camera is inspecting is shown. After 'stop' icon is clicked, frame size, frame rate and exposure time are adjusted appropriately, and then 'apply' icon is clicked. In this thesis, the frame size is 1280×1024, the frame rate is 300 fps, and exposure time is 997usec. It is necessary to make exposure time as long as possible to get a bright and clear image. Then the adjusted live image is exhibited in the window.

Initiate the object to move such as shooting a dart or throwing a ball. At the same time click the 'record.' Then the recording video is constructed. If the recorded video is desired to be shown, click 'play.' The necessary images among large number of frames are chosen and saved by clicking 'file,' and 'save.' The video is saved to '.avi' type, and it is possible to analyze the video to get the velocity or trace of the moving object. Fig 3-1 is the snapshot of high speed image of projectile model #6. All snapshot of projectile models can be seen at Appendix B-1.

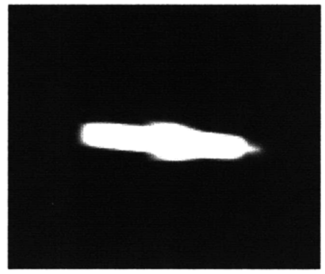


Figure 3-1: Snapshot of high speed imaging of projectile model #6

High Speed Image Analysis

In this thesis, ProAnalyst®, the motion analysis software by Xcitex, Inc. has been used for analyzing the high speed videos to get the velocity and/or trajectory of the projectiles.

ProAnalyst® provides motion analysis tools that can be applied to any video or image sequence, regardless of content or acquisition method. it enables the user to track features without having to use special markers, such as ping-pong balls, in the experimental setup. The Automatic Tracking tools find and track natural features in each video frame. [8] Fig 3-2 is the trajectory of model #1, and the trajectory of whole models can be seen at Appendix B-2.

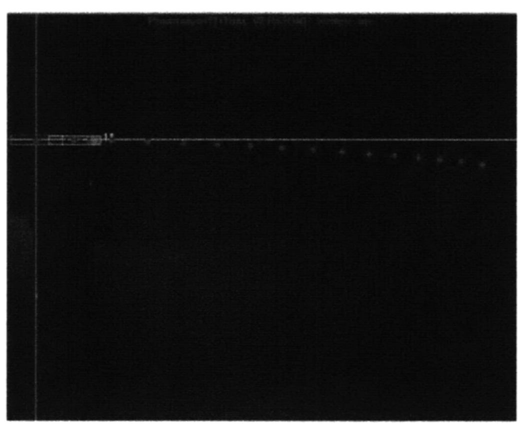


Figure 3-2: Trajectory of flying projectile model #1

3.1.3 Distance / Initial Kinetic Energy Calculation

Description

The value, distance divided by initial kinetic energy presents how far each projectile model fly with the same amount of energy. Higher value means that the dart model has better potential for flying farther with the same amount of energy. The data of distance and initial velocity were already attained, so the measurement of the mass of each projectile model was only needed for this test. The measurement of the mass for each model should be conformed precisely, because slight difference of the mass causes significant change of the value of kinetic energy, $\frac{1}{2}mv^2$.

Procedure

The mass of projectiles were determined by weighting a sample on a laboratory balance which has a significant figure of 4 decimal places. The distance and initial velocity were measured according to the procedure of 3.1.1 and 3.1.2

3.1.4 Drag Coefficient Calculation

Description

Drag Coefficient is shape related factor and it is always associated with a particular surface area. In the drag coefficient equation,

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A} \tag{3.1}$$

F_d is the drag force, which is by definition the force component in the direction of the flow velocity, ρ is the mass density of the fluid, v is the speed of the object relative to the fluid, and A is the reference area. C_d is not a constant, but varies as a function of speed, flow direction, object shape, fluid density and viscosity. Speed is the only variable among those in flying projectiles. The purpose of calculating drag coefficients of projectile models is comparing, so it is sufficient to calculate average drag coefficient of each projectile model.

Procedure

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A} \quad (3.1)$$

$$F_d = m \times a_d \quad (3.2)$$

m is a mass of each projectile model, and a_d is an acceleration of each drag force which is generated when projectile flies in air. Masses of projectiles are measured by laboratory balance, and acceleration of drag force could be calculated by the following equation.

$$a_d = -\frac{dv}{dt} \cong -\frac{\Delta v}{\Delta t} \quad (3.3)$$

It can be assumed that the only force that makes change in the horizontal velocity is a drag force, and the projectiles' motion could be regarded as uniformly accelerated motion in initial short time. Δt is a time for the flying projectile while its velocity changes by Δv. It is certain that the direction of acceleration of drag force is opposite to the direction of flying projectiles, so the negative sign could be multiplied.

ρ is a density of air, and it varies with the temperature and pressure.

$$\rho = \frac{p}{R \times T} \quad (3.4)$$

The air temperature during test was about 20°C, and the air pressure was 1atm, so, 1.204kg/m^3 could be chosen as density of air.

The v in denominator is the speed of the projectile relative to the air which is measured at 3.1.2.

A is not the area of tip, but the reference area. It is the area which is shown in front of the flying projectiles. This could be attained by measuring projectile models.

3.2 Accuracy Evaluation

Description

It indicates how similar trace and direction each projectile model flies, that is, straightness. Projectile models were shot at the same mounted place, with the same angle of toy gun aiming for the same target. It is undesired that projectiles fly to the unexpected direction, so higher accuracy is better for projectile models.

Figure 3-3: Accuracy test procedure

Procedure

10 times for each dart model are shot 2m from a 110mm radius circle with a mounted gun at 1m high. Values have been calculated as mathematical variance with the distances between the center and the marks which darts made when they bumped into the dart board. $\Sigma(\text{distance} - \text{average distance})^2$

3.3 Safety Evaluation

Description

Safety standard prescribes the safety factor is related to the kinetic energy and the tip area of projectiles. Significantly high kinetic energy and tip with minute area should be prohibited to protect player from injury, even though higher energy and/or smaller tip area creates better performance of projectiles. The data should be complied by the safety standard by Hasbro, Inc.

Procedure

Kinetic energy of each projectile model is calculated by measuring average velocity and mass of each model as explained above. The projectile kinetic energy density is the kinetic energy of the projectile divided by its contact area. The contact area could be measured through the marks which darts made when they bumped into the dart board. The area is average of each 10 marks.

3.4 Supplementary Evaluation

Description

Additionally, evaluation for comparing the production error and performing error was progressed. Production error means that the difference of performances among the several projectiles of the same model. The term describes how similar performance of projectiles can be attained by production. Besides, performing error means the difference of performances among the several playing with the one projectile.

Procedure

Projectile model #1, Sonic Micro Dart® in the state of the art, was chosen for the test. It is certain that the developed and prototyped projectiles have much more production error, so they are not appropriate for the evaluation. 20 Sonic Micro Darts® were shot once for each at 1.4m height indoors with the gun which is mounted horizontally to the ground exactly the same condition to the distance measuring procedure, 3.1.1. After that, the 20 distances of flight were measured. On the other hand, 1 Sonic Micro Darts® was shot 20 times at the same condition, and the 20 distances of flight were measured.

Chapter4

Concept development Procedure

This chapter includes the full process steps of concept development from state-of-the-art searches to evaluation. This phase is divided by 4 parts, state-of-the-art product searches, initial models development, modified models development, and final model development. Each development involves brainstorming, distilling, concept sketch, prototyping, performance test, and evaluation.

4.1 State of the Art

To become accustomed with the state-of-the-art toy products and their technology, frequent visiting to toy stores including Toys "R" Us and toy manufacturer, Hasbro, Inc. was performed. The meeting with current toy developers at Hasbro, Inc. helped to be familiar with state-of-the-art technology and learn toy design process. In addition, toy patent searches and detailed listings and specifications of the complete line of Nerf® were performed at the beginning of this research.

Nerf®, made of foam material, is a kind of toy, to make safe indoor play possible even though it is played as shooting. Most of the toys are a variety of foam-based weaponry, but there were also several different styles of Nerf® toys, such as balls for sports like football, basketball, and others. The most prominent of the toys are the "dart guns" also called as blasters that shoot bullets made from Nerf® foam.

Nerf® toys are made from a solid, spongy cellular material created by the reaction of polyester with a diisocyanate while carbon dioxide is liberated by the reaction of a carboxyl with the isocyanate. Polyester resin reacts with a compound while CO_2 is concurrently released by another reaction. It is this gas that produces open pockets within the polyurethane that, in turn, creates the material light and soft. [9]

Over the years, the company has persisted to enlarge the line, adding new appearances to existing products. The current line of Nerf® products ranges from various sport balls, dart guns with both dart and ball projectile, and, even to accessories for video game. The state-of-the-art Nerf® N-STRIKE guns are shown in Figure 4-1. [10]

 NERF N-STRIKE LONGSHOT CS-6 It is more than three feet long and can launch foam arrows up to 35 feet away.	 NERF N-STRIKE SECRET STRIKE AS-1 It offers a powerful blast in a stealth size.	 NERF N-STRIKE MAVERICK It features a six-dart rotating barrel with easy flip loading
 NERF N-STRIKE VULCAN EBF-25 It is a battery-powered blast, and can fire at a rate of up to three darts per second.	 NERF N-STRIKE RECON CS-6 It has five interchangeable parts that take apart and reassemble any way user wants.	 NERF N-STRIKE SWITCH SHOT EX-3 It is air-powered, foam-dart blaster that converts into a controller for Wii Console video game system.

Figure 4-1 Overview of Nerf® N-STRIKE™ Products [10]

Among those toy guns, Nerf® N-STRIKE Nite Finder EX-3™, the air compressed dart gun was chosen as reference testing gun for projectile evaluation test. It is one of the Nerf®'s classic pistol-like blaster integrated light painter (LED) and it features a top-mounted accessory rail. The Nite Finder™ can accept some type of Nerf® micro dart™, including Sonic and Sucker Darts™. The Figure 4-2 shows this product. To cock the gun, the user pulls a cocking ring, which remains in position until the trigger is pulled.

Figure 4-2 Nerf® N-STRIKE Nite Finder EX-3™

The product was chosen because it is small and easy to play, and it boasts long range and good accuracy. It seems likes that its simple mechanism and inexpensive price makes it an excellent candidate for choosing to the customer as well. There are numerous users who modify the Nerf® gun to get better performance, but the modification of this product only increases its range by a few feet and the blaster is even louder to operate when modified. Therefore, the product is regarded as the optimum toy gun for using as reference to evaluate darts.

On the other hand, several kinds of darts are in the state of the art. The darts are divided by two parts according to the size, micro dart™ and mega missile™. Comparison between the micro darts™ and mega missile™ can be made through Figure 4-3. There are only one kind of mega dart™ and more than 4 kinds of micro dart™, so the modification is progressed on the micro darts. 4 types of micro darts™ which have different shape can be found in the market. Micro darts™ which have a suction cup on the head to be attached, sonic micro darts™ are designed to whistle as they fly, streamline darts™ are designed for enhanced accuracy and distance, and tagger micro darts™ have tag on the head to stick to anything fuzzy. In addition, there is glow darts™ in the same shape of micro darts and have glow-in-the-dark labels.

Figure 4-3 Nerf® N-STRIKE™ UNITY POWER SYSTEM

			
Micro Dart	Sonic Micro Dart	Streamline Dart	Tagger Micro Dart

Figure 4-4 Nerf® Micro Darts™

4.2 Part 1 – Initial Models

Brainstorming

After searching and understanding state-of-the-art toy products and the technologies, brainstorming was the following step for generating conceptual designs. Brainstorming step was necessary to establish diverse and creative designs. There is no standard rule in brainstorming, but a suggested format proposed by Rossiter and Lilien [11] was loosely followed for this step. Osborn's book Applied Imagination fueled the spread of group brainstorming as a tool for increasing creativity in organizations. He proposed four rules for these sessions: don't criticize, quantity is wanted, combine and improve suggested ideas, and say all ideas that come to mind, no matter how wild. [12]

After acquaintance with the brainstorming instructions which are essential to maximize creative idea output, the initial ideas were generated individually. The group in CAD lab interacted to amalgamate and refine ideas. Finally, As a result of brainstorming, more than 30 kinds of shape for darts are finally developed.

Distilling

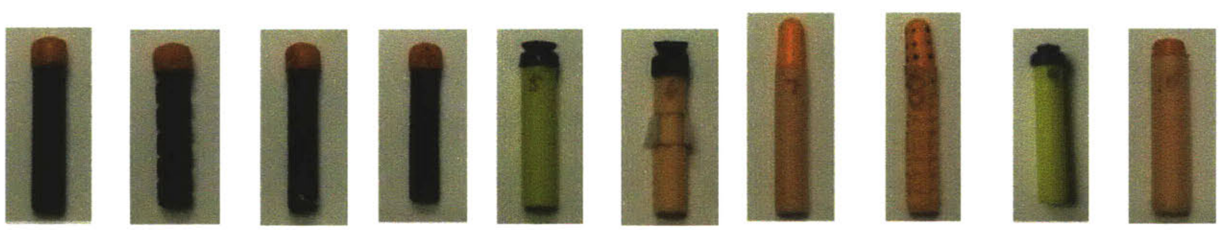
It is condensed that from over 30 original concepts to 10 potential concepts which do not have more than two reformed item to evaluate the effect of each reformation. The chosen models have not the combination of head replacement and screw, but only head replacement or only screw or only wings. The 10 potential concepts are following.

- Deeply screwed (1.5mm) ②
- Lightly screwed (0.5mm) and filled up the hole on the head ③
- Hole spread ④
- Attached 4 wings on the middle of the body ⑥
- Replaced the head with ear plug ⑦

- Replaced the head with ear plug & grooved on the body ⑧
- Carved sucker head ⑨
- Filled up the hole on the head and adjusted for the gun ⑩
- Shortened to 2/3 length
- Attached 4 wings on the tail

Prototyping

From 10 concepts, 8 Kinds of models are selected for evaluation test, and 10 projectiles for each model are fabricated. However, 2/3 length and attachment of 4 wings on the tail do not applied by the reference toy gun, so removed from the list. To compare with the performance of state-of-the-art product, sonic micro dart™ ① and micro dart™ ⑤ were combined to the group of initial model.



① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Figure 4-5 Prototyped initial models for evaluation

Evaluation Test

The performances tests of distance, accuracy, and safety according to the methodologies describe in chapter3 were performed with the initially prototyped models in Figure 4-5.

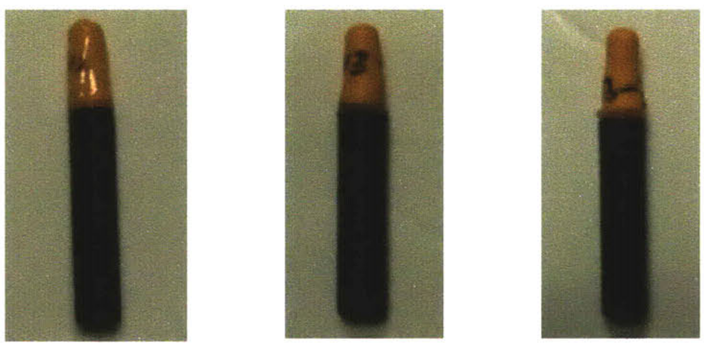
Analysis and Discussion of Evaluation test results

The results of the performances tests were considered and investigated to modify the initial models. The meeting with current toy developers at Hasbro, Inc. helped to analyze the results of evaluation test, and gave suggestions and advices for further development. Considering and adopting these suggestions the concepts for modification were developed.

4.3 Part 2 – Modification

Reconsideration and Prototyping

Setting the model #7 which is replaced the head with memory foam ear plug as a basis for modification because of great performance of farther flying; the revisions for improving accuracy performance were conducted. To prevent the deformation of soft memory foam head during flight, several designs including coating head with glue, putting pin in the head were prototyped. In addition, the washers with diverse masses were installed between head and body to create higher mass.



⑫ ⑬-① ⑬-③

Figure 4-6 Prototyped modified models for evaluation

Evaluation Test

The performances tests of distance, accuracy, and safety according to the methodologies describe in chapter3 are performed with the prototyped modified models in Figure 4-6.

Analysis and Discussion of Evaluation test results

The results of the performances tests were considered and investigated for getting final model. Among 3 prototyped modified models, the models with installing pin inside of head were selected for analyzing rather than the model with coated head because of prominent performances.

4.4 Final Model

Concept Sketch

Throughout the evaluation of initial models and modified models, the concepts for final model were developed. The concepts of final model were sketched.

Concept Sketch Refinement and further

The concept sketches are revised for several times and refined. Eventually the refined concept sketch was attained and CAD of final model was obtained. After that the future work were considered.

Chapter 5

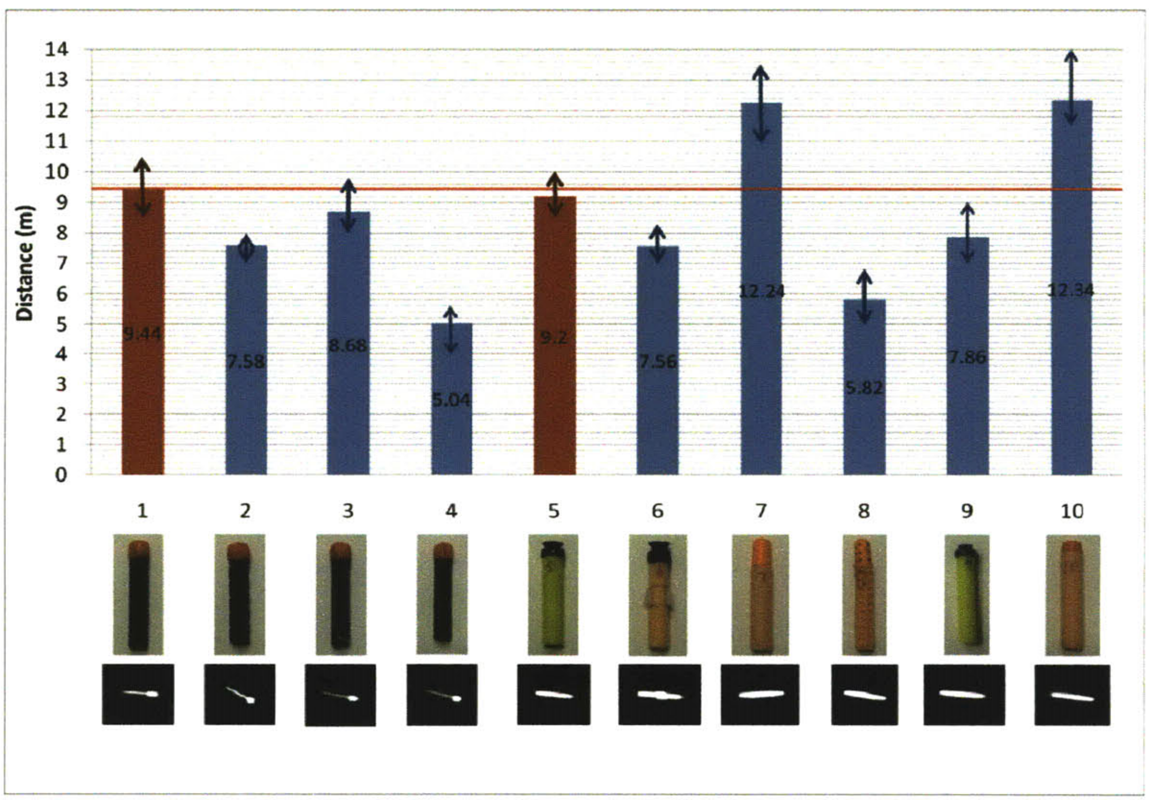
Result and Analysis

This chapter contains the result of evaluation test of projectile models to approach the conclusion. The results of distance of flight evaluations including distance measurement, velocity measurement, distance per kinetic energy calculation, drag coefficient calculation; accuracy evaluation; and safety evaluation for initial models and modified models are described in detail, and the pertinent reasons causing that results are explained specifically.

5.1 Part 1 – Initial Models

5.1.1 Distance of Flight

Distance



Graph 5-1 Distances of Flying Projectiles

Graph 5-1 shows the distance of flight of projectile models. The X axis indicates each projectile and the Y axis indicates the distance in meter scale. Under the X axis, the photograph of each model and snapshot of each flying model are presented. The full size snapshots of projectiles can be found in Appendix B-1. The arrow on the top of each bar graph shows the dispersion of distance data. Model #1 and #5 are the state-of-the-art darts in market now, so the better one of those is chosen as a point of reference, and the red line shows the distance of reference. As can be seen, model #10 and #7 fly farthest, and these models are better than the reference model by 30.72%, and 29.66%. This improvement is worthy of close attention, because it is almost certain that 30.72% farther distance of flight satisfies customers expectation very well.

The reasons of that the model #10 and #7 fly farthest can be divided into two parts. First, the models are closer to streamline shape than other models having bump between head and body. The streamline shape allows dart to sustain less resistive force when it flies in air. As air drag is disembogued along the surface of the body, vortex scarcely happens in the motion of streamline shape objects. Therefore the resistive force can be reduced, and the farther range of flight can be obtained. The drag coefficient of each projectile model can be seen in the last part of 5.1.1.

	Mass (g)
1	1.33930
2	1.41150
3	1.58150
4	1.44820
5	1.34930
6	1.69480
7	0.69890
8	0.95500
9	1.57690
10	0.90700

Table 5-1 Masses of Projectile Models

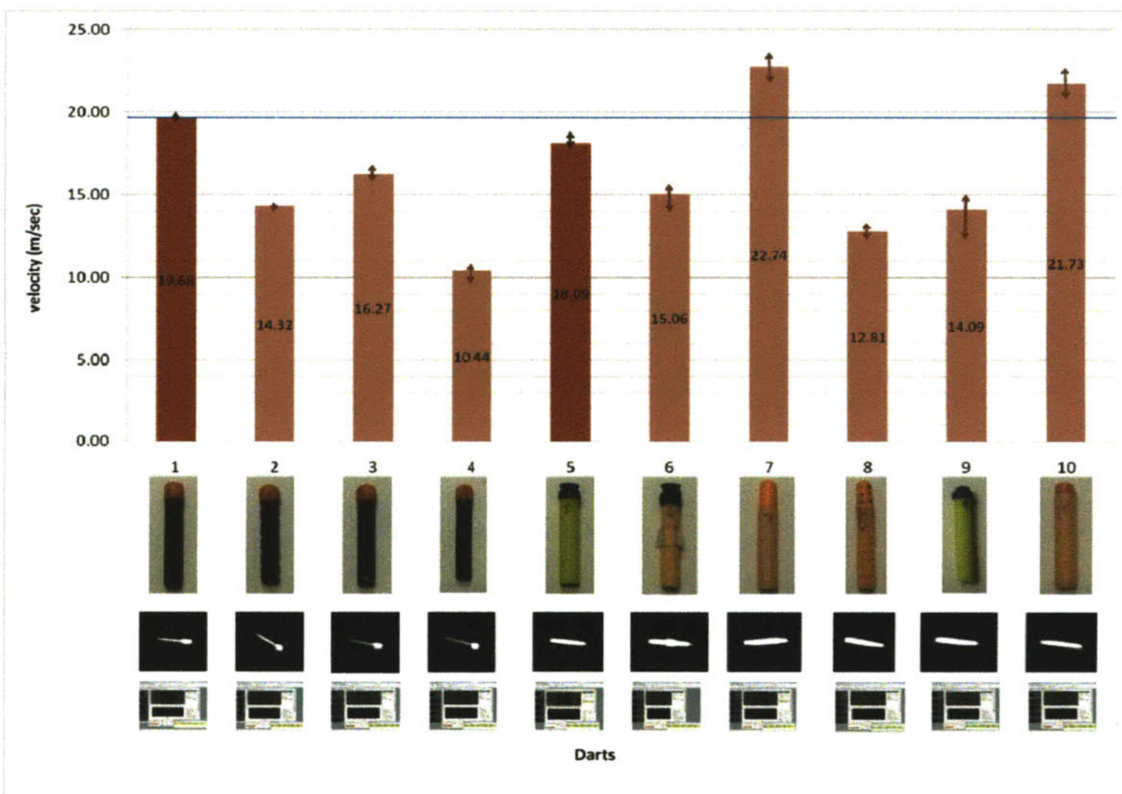
The second reason of farther flight should be low mass of models. As can be seen on Table 5-1, model #7 is 0.6989g and #10 is 0.9070g, and these show lower masses by

50.8%, and 36.1%, comparing with other models' average mass, 1.4196g. Low mass enables projectiles attain higher velocity from the same amount of potential energy of toy gun. It is undeniable that the higher velocity allows darts to fly farther directly. The velocity of each projectile model is described in the following part.

In addition, the uniform density distribution could affect the distance of flight. As shown by the snapshot of the flying darts under the photo of each dart model in graph1 and/or in Appendix B-1, model #7 and #10 fly straightly comparing model #2 which flies seriously tilted because of large difference of mass and/or density between the head and body materials.

On the other hand, the projectile models which have rough surface such as model #2, #4, #8 shows shorter distance of flight. It seems likely the reason of that is the influence of high drag force.

Initial Velocity



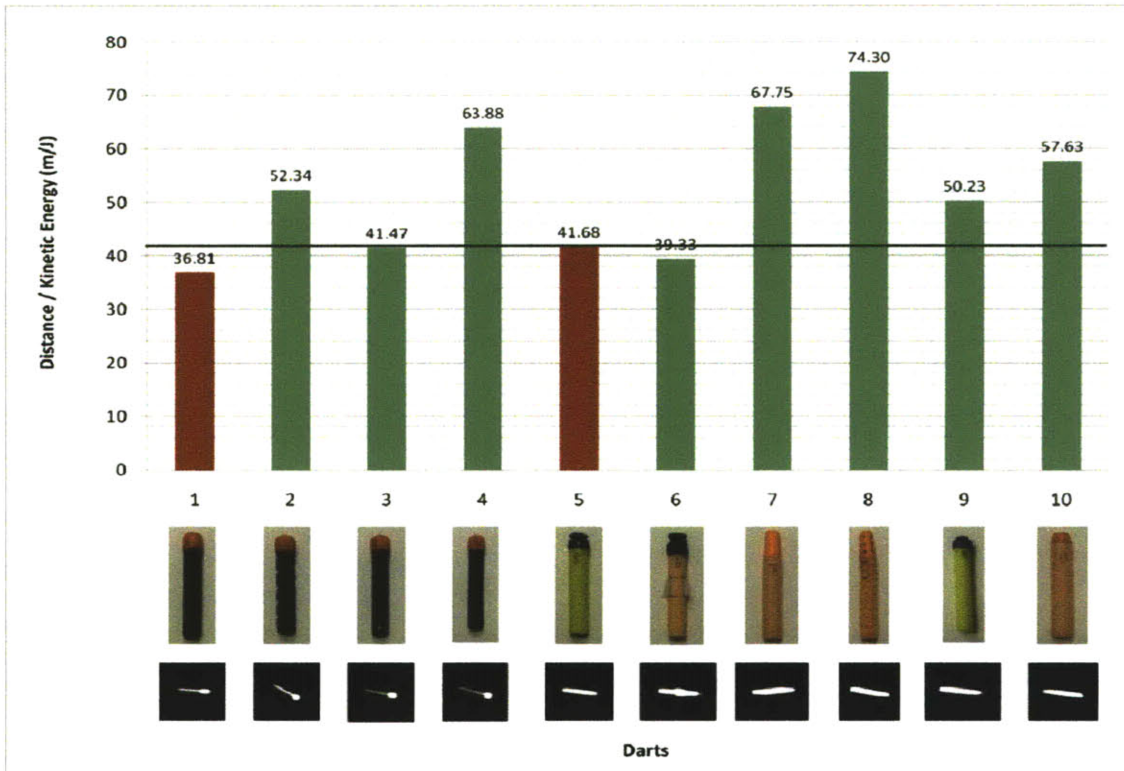
Graph 5-2 Initial Velocities of Flying Projectiles

Graph 5-2 provides the initial velocity of each projectile model. The X axis shows each projectile and the Y axis shows the initial velocity scaled meter/second. The photographs under each projectile are the snapshots of flying dart models taken by high speed camera and the trajectories of flying projectiles analyzed by "ProAnalyst®." The full trajectory images of dart models can be found in Appendix B-2. The arrows in the top of each bar graph show dispersion of velocity data and the blue horizontal line shows the reference as well. #1 and #5 are darts in market now, so the better one of those is chosen as a point of reference. As can be seen, this graph is similar to the distance graph. Model #7 presents the highest initial velocity, 22.74m/s and model #10 presents the second highest initial velocity, 21.73m/s, and these are much higher than reference.

Even though there has been no demand for initial velocity, the measurement of initial velocity is significant to comprehend distance of flight data and calculate initial kinetic energy. Projectiles having higher velocity imply that the projectiles convert the potential energy of the gun, which is generated by the triggering force, into the kinetic energy of projectiles well. Therefore, more energy to fly farther can be provided for the projectiles.

The rationales behind of how to convert the potential energy of the gun into the kinetic energy of darts well should be related with the design of dart models. The streamline shape and non existence of hole should influence higher initial velocity. As mentioned above, the streamline shape enables dart to uphold less resistive force when it flies in air. Because air drag is disembogued along the surface of the body, vortex scarcely happens in the motion of streamline shape objects. Therefore the resistive force can be reduced, and the lost of energy can be reduced. In addition, holes which allow the pressed air, the source of energy, to deflate are blocked in model # 10 and there is no hole in model # 7 at all. Because of these, the models provide higher initial velocity.

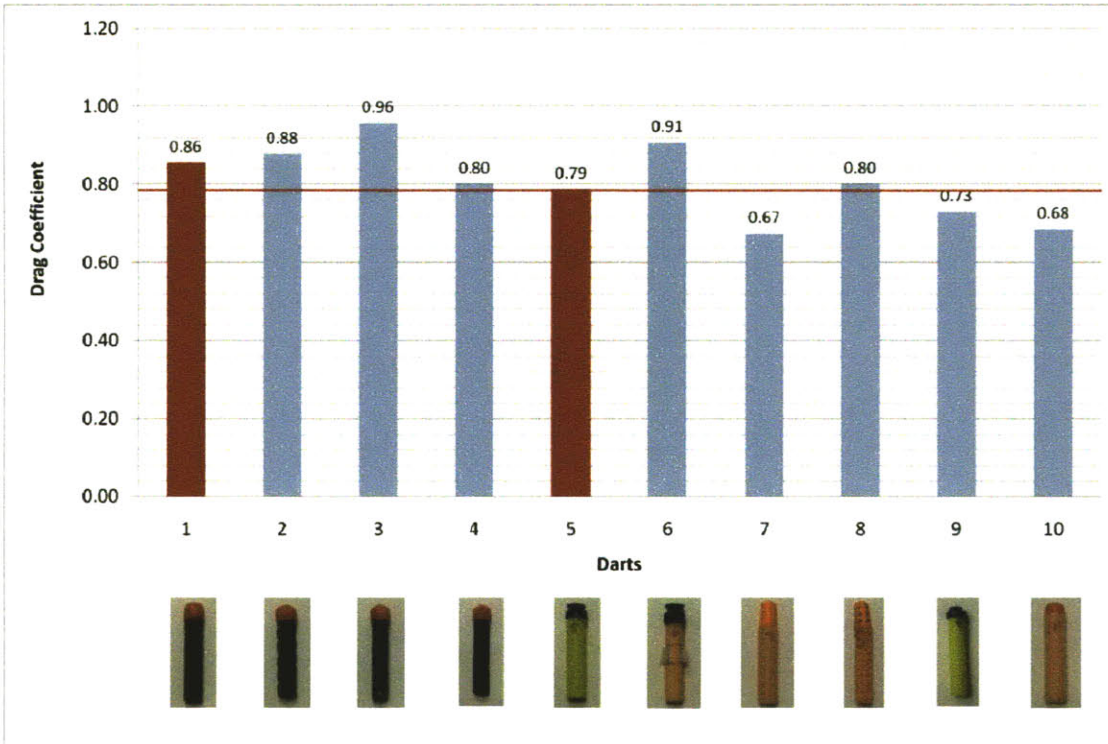
Distance / Initial Kinetic Energy



Graph 5-3 Distance/Initial Kinetic Energy

Graph 5-3 illustrates the distance per initial kinetic energy of each dart model. The X axis shows each projectile and the Y axis shows the value, distance per kinetic energy scaled meter per Joule. #1 and #5 are darts in market now, so the better one of those is chosen as a point of reference. The horizontal line shows the reference as well. As can be seen, most of newly designed projectiles have better data than #1 and #5. This is mostly because of less mass shown in Table 5-1 which affects to generate less kinetic energy. It is certain that less velocity and higher distance affect the value, distance per kinetic energy as well. Model #8, #7, and #4 show high quality performances. Model #8 and #4 have low velocity, and short distance, so it is not necessary to pay attention to the models, but model #7 seems likely noticeable because it has high velocity and long distance. Long distance, high velocity, and low mass result in the high value of distance per initial kinetic energy, and those are desirable.

Drag Coefficient



Graph 5-4 Drag Coefficients of Projectiles

Graph 5-4 describes the drag coefficient of projectile models. The X axis shows each projectile and the Y axis shows the drag coefficient which is dimensionless quantity. Model #1 and #5 are the state-of-the-art darts, so the better one of those is chosen as a point of reference. As can be seen, the range of drag coefficient of each projectile model, which has roughly cylindrical shape, is from 0.67 to 0.96, and the average of drag coefficient of each projectile model is 0.81.

Even though it is not completely accurate drag coefficient data of darts, because several assumptions: the only force that makes change in the horizontal velocity is a drag force; the projectiles' motion could be regarded as uniformly accelerated motion during initial short time were established for calculating the drag coefficient, the calculated data meet the terms in documentations including the paper by Dennis and Chang [13], and Table 2-2 well. This result improves that the assumptions are reasonable and the drag coefficient data can be reliable. In the mean time, the comparison between the drag coefficient data of projectile models is worthy to be performed.

The red line shows the drag coefficient of reference. Model #7 and #10 present the smallest drag coefficient, and it is already proved previously that the models have great performance of flight: farther range of flying and higher initial velocity. It seems likely that the significant rationale of that the models have small drag coefficient is the streamline-like shape which boasts the smallest drag force, and non-existence of bump between head and body which increases the skin friction drag could be the additionally reason.

Through this graph, it is confirmed that the rough surface of flying object make larger drag force than smooth surface. That model #2, #3, #4, and #8 show higher drag coefficient could be the evidence for that, and specifically when comparing the model #7, and #8 which have the same shapes except for the grooves on the surface of model #8, #8 has larger drag coefficient than #7 by 19.4%. The rough surface generates more vortex than the smooth surface. This drag because of surface roughness is called skin friction drag.

The effect of hole in the body can be verified through the data. Comparing model #2 which has deep screw on the surface and a hole in the head and model #3 which has light screw on the surface and no hole in the head, model #3 has larger drag coefficient than model #2. If considering only the effect of screw, it is certain that the deep screw, rougher surface, generate more vortex than light screw, and model # 2 should have larger drag coefficient.

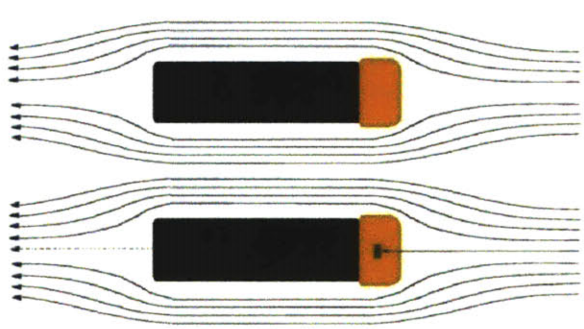


Figure 5-1 Air Flow around Projectile Models without Hole (up) and with Hole (down)

However, the hole in the head allows the air flow, and drag to be disembogued through the hole as shown in Fig 5-1, and finally reduce the drag force. Therefore model #2 has smaller drag coefficient than model #3.

Comparing model #5 and #6, the effect of Attachment of wings to the drag coefficient can be detected. The drag coefficient of model #6 which has 4 wings on the middle of the body is larger than model #5 which has the same shape to the model #6 except for the wings. It seems likely that the wings do not increase lift force, but increase air resistive force. In this situation, the wings could not fulfill its role, but the presence of multiple bodies just created large vortex by interference drag

In this graph, the difference of drag coefficient data between model #5 and #9 which has the carve suction cup from the model #5 can be the substantiation of shape related drag coefficient with the same reference area. The models have the same reference area, 0.000153938m^2, but the shape of head and the length is different as shown in Fig 5-2. Considering the length of two models, the model #9 should have larger drag coefficient than #5, but the result is opposite. It seems likely that the shape of the front area cause the result that the model #9 has smaller drag coefficient than model #5.

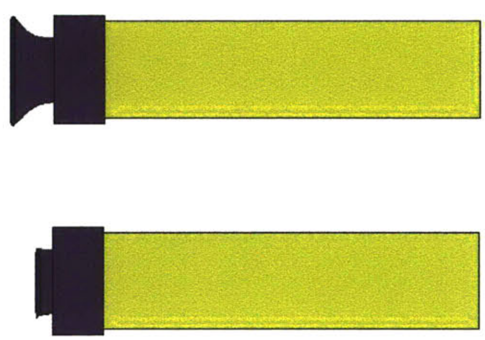
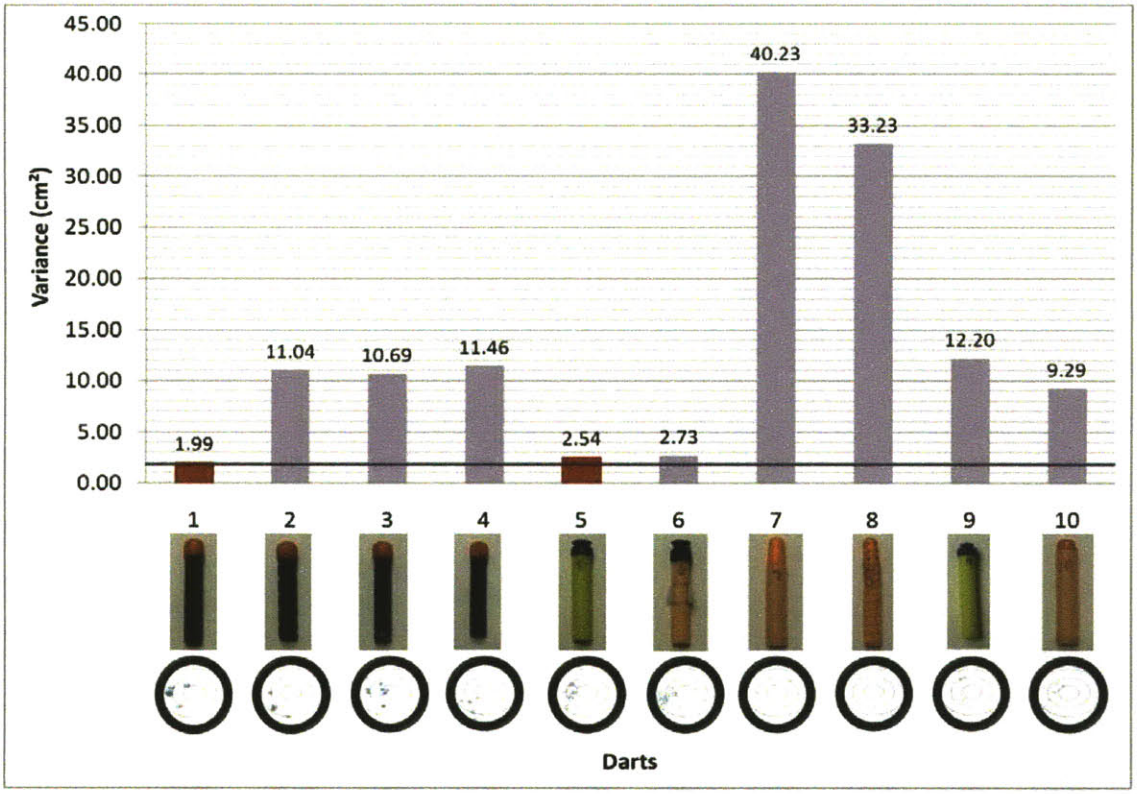


Figure 5-2 The Shape of Projectile Model #5 (up) and #9 (down)

As can be seen, the drag coefficient is in inverse proportion to the distance. The less value of drag coefficient should be required to reduce the drag force and obtain better performance of flying as the final point.

5.1.2 Accuracy



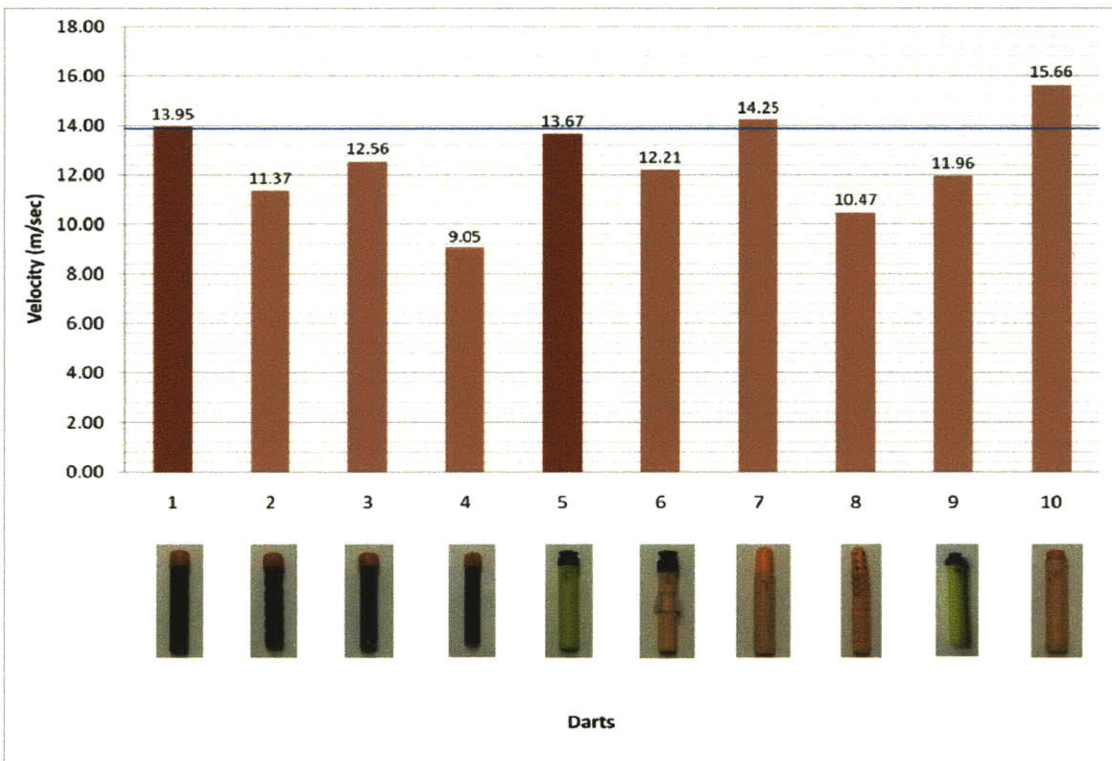
Graph 5-5 Accuracies of Projectiles (Variances of Marks)

Graph 5-5 demonstrates accuracy of each projectile model, that is, repeatability by presenting the variance of marks which are generated by bumping projectiles into the wall. The X axis shows each dart and the Y axis shows variance, Σ (distance – average distance)^2, scaled square cm. The graph presents how darts fly in similar way and direction. #1 has the best repeatability and #5 and #6 are fine. However, #7 and #10 which have good performance of distance and initial velocity and distance per kinetic energy do not show good accuracy and/or repeatability. The larger pictures of dart boards with marks which darts made when they bump to the wall are attached in Appendix B-3.

Although newly designed models provide enhanced performance of distance, those models do not present passable accuracy. This result can be explained by low mass, and deformation of head during flight. Model #7 and #8 which shows the worst accuracy among dart models consist of ear plug heads which are composed of memory foam. The memory foam is significantly flexible and deformable, so it can be bent by slight air pressure. During the flight of darts in air, they should be affected by air flow and resistive, and be deformed to crooked shape. In addition, the low mass implies that it is difficult for darts to maintain those own ways. Low mass let darts be influenced by air condition easily.

5.1.3 Safety

Average Velocity



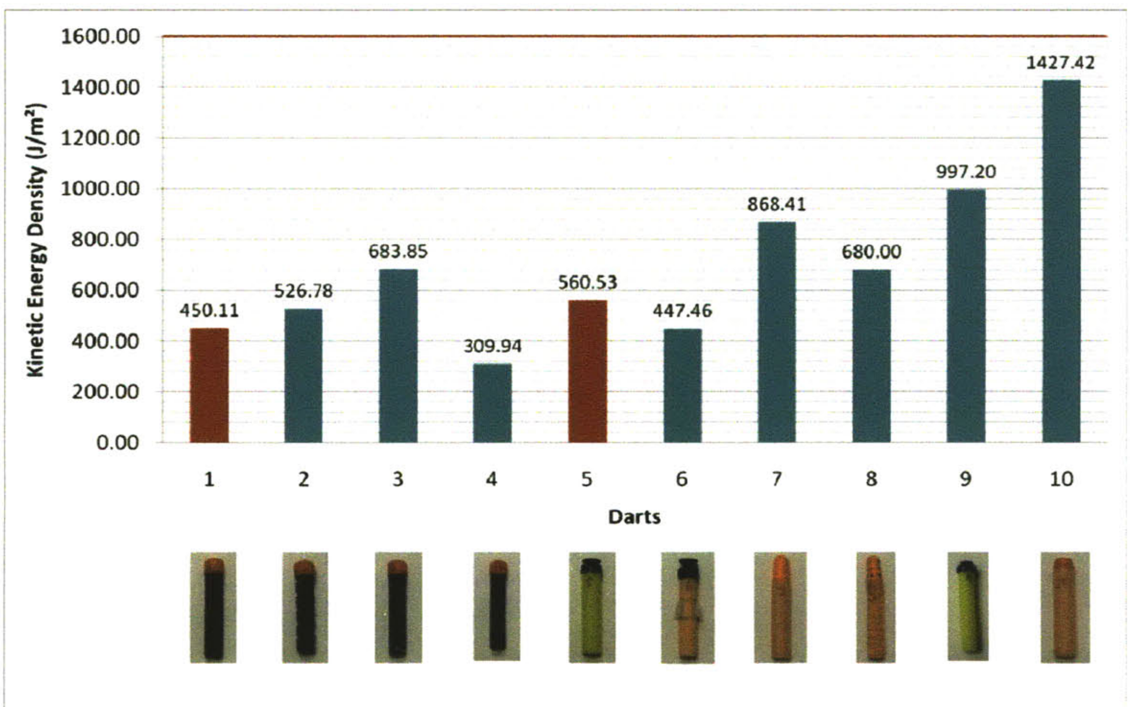
Graph 5-6 Average Velocities of Flying Projectiles

Graph 5-6 provides the average velocity of flying projectile models. The X axis shows each projectile and the Y axis shows the average velocity scaled meter per second. The arrows in the top of each bar graph show variance and the blue horizontal line shows the reference as well. Model #1 and #5 are darts in market now, so the better one of those is chosen as a point of reference.

Strictly speaking, these are not the average velocity. These velocity data are not the average of all velocity of flying projectile models, but the average of velocity of flying projectiles for preliminary 1m distance, from getting out of the toy gun to 1m far. The rationale behind choosing these data as average velocity is that darts are not always played in the distance, but even played to shoot other close players. Using this average velocity for calculating the kinetic energy density for safety test should be more appropriate than using the average velocity of flying projectiles during whole flight.

The graph of average velocity is similar to the graph of initial velocity, but it is not perfectly in direct proportion to the initial velocity. Because of the difference of drag force which is applied to the projectile, the decrease of velocity varies.

Kinetic Energy Density



Graph 5-7 Kinetic Energy Densities of Projectiles

The graph 5-7 provides the kinetic energy densities of dart models. The X axis indicates each projectile and the Y axis indicates the kinetic energy density in joule per square meter scale. As can be seen, every model does not exceed the limit kinetic energy density, 1600J/m^2, that is it complies the safety standard well.

The kinetic energy of model #1 is 0.13J, according to the "Corporate Quality Assurance, Safety and Reliability Specification, SRS-045, Projectiles" [3], the minimum allowable tip radius is 5mm, and the tip radius of model #1 is 9.6mm, so it can be confirmed as safe projectile toy. From model #2 to model #6, these projectiles have larger than 7mm tip radius, and less than 0.15J kinetic energy, so these models can be demonstrated as safe. However, model #7, #8, #9, and #10 are required to be verified. Model #7 has kinetic energy of 0.071J, so its tip radius should be larger than 4mm to conform the safety standard. As its tip radius is measured as 5.1mm, the model can be regarded as safe. Model #8 has kinetic energy of 0.052J, and tip radius of 4.95mm which is larger than the minimum allowable radius, 4mm. The kinetic energy of model #9 is 0.113J and the tip radius of the model is 6mm which is longer than the minimum allowable radius, so the model #9 meets the terms of the safety standard as well. However, model #10 which has 0.111J of kinetic energy has the 4.98mm tip radius which is slightly less than the minimum allowable radius, 5mm. It is slight and in the scope of measurement error, and it has resilient tip so it seems likely to be ignored. However, it is certain that the projectile model #10 is not safer than the state-of-the-art toy projectiles. All kinetic energy and tip area data can be seen Appendix C-4 and C-7.

5.1.4 Total Result

Table 5-2 shows the grade of each model's performance as a result of evaluation. The projectile model which has the highest value of each evaluation is set as 10 and other models are set as 0 to 10 according to the ratio of those models' analysis value to the highest value. Lower is better for drag coefficient, accuracy, and kinetic energy density, so the scores for these analysis are multiplied by -1. The total scores are sum of each score, and finally the rank of each model's performance can be achieved.

	Distance	Initial v	D/E	C_d	Accuracy	Safety	SUM	RANK
1	7.6499	8.6550	4.8990	-8.9402	-0.4956	-3.1533	8.61	1
2	6.1426	6.2998	7.0449	-9.1708	-2.7449	-3.6904	3.88	7
3	7.0340	7.1549	5.5819	-10	-2.6583	-4.7908	2.32	8
4	4.0843	4.5908	8.5975	-8.3571	-2.8476	-2.1713	3.90	6
5	7.4554	7.9548	5.6100	-8.2249	-0.6326	-3.9269	8.24	2
6	6.1264	6.6234	5.2940	-9.4744	-0.6778	-3.1347	4.76	5
7	9.9190	10	9.1182	-7.0472	-10	-6.0838	5.91	4
8	4.7164	5.6328	10	-8.3593	-8.2599	-4.7638	-1.03	10
9	6.3695	6.1955	6.7610	-7.6272	-3.0326	-6.9861	1.68	9
10	10	9.5563	7.7565	-7.1606	-2.3091	-10	7.84	3

Table 5-2 Score of Each Projectile Model's Performance

As can be seen in Table 5-2, model #10 shows the best performance among newly designed models. The underlying principle behind this would be the streamline shape. It is certain that reduced resistive force including air drag from the close to streamline shape provides farther distance of flight. Model #7 is the second best among innovative models, in view of the fact that the streamline shape, uniform density, and low mass enable the model to perform flying farther. However, there is no projectile model which has better performance than the state-of-the-art models, #1 and #5. This is because that the newly designed models do not have proper accuracy. The accuracy of innovative models is seriously worse than that of the state-of-the-art models. This fact would be confirmed after examining the score of each dart's distance of flight performance.

	Distance	Initial v	D/E	C_d	SUM	RANK
1	7.6499	8.6550	4.8990	-8.9402	12.26	4
2	6.1426	6.2998	7.0449	-9.1708	10.32	7
3	7.0340	7.1549	5.5819	-10	9.77	8
4	4.0843	4.5908	8.5975	-8.3571	8.92	9
5	7.4554	7.9548	5.6100	-8.2249	12.80	3
6	6.1264	6.6234	5.2940	-9.4744	8.57	10
7	9.9190	10	9.1182	-7.0472	21.99	1
8	4.7164	5.6328	10	-8.3593	11.99	5
9	6.3695	6.1955	6.7610	-7.6272	11.70	6
10	10	9.5563	7.7565	-7.1606	20.15	2

Table 5-3 Score of Each Projectile Model's Performance of Distance

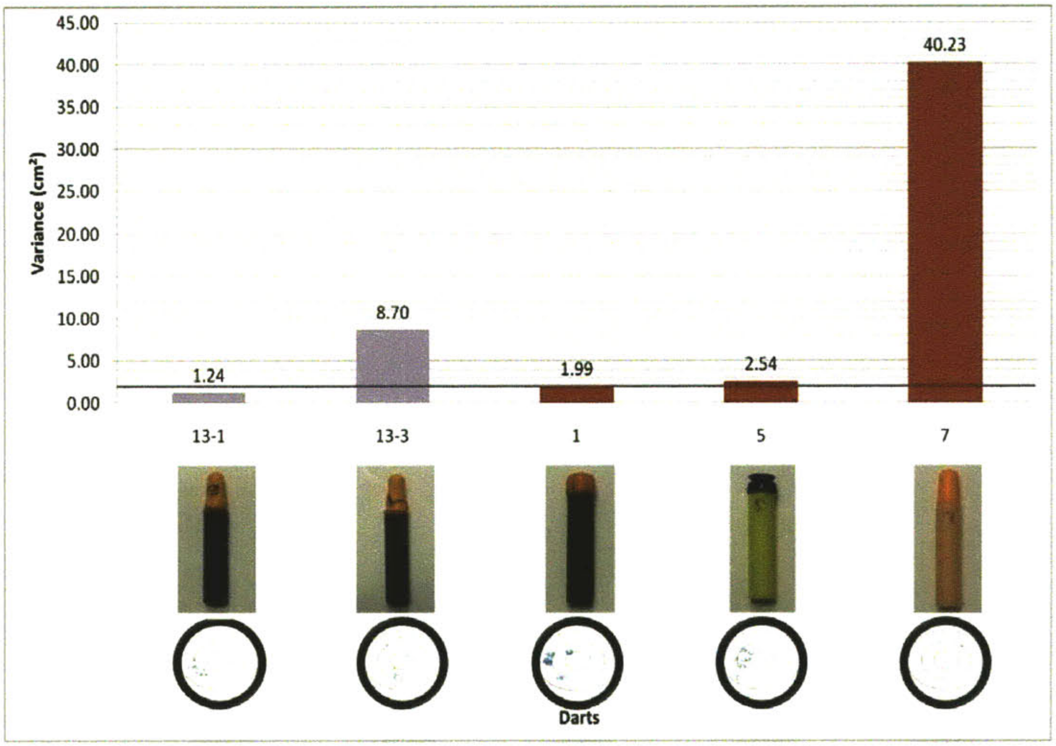
Table 5-3 shows the scores of each model for distance of flight evaluation only. As can be seen, model #7 shows the best performance of distance. As mentioned above, the streamline shape, uniform density, and low mass enable the model perform to fly farther distance. However, an inexcusable accuracy depreciates the total performance of the model #7. It seems likely that the deformation of head during flight causes the depreciation of the accuracy. Soft head composed of memory foam was bended by air pressure easily, and it makes the darts fly obliquely. Therefore, unsatisfied accuracy is observed for the model. Moreover, the low mass of the model #7 could be the explanation of accuracy as well. Having low mass allows the model to be subject to getting influence of external factors, such as air flow, and finally makes it hard to fly to its own direction.

Model #10 has the second best performance of flying farther, and longer range of flight than the state-of-the-art projectiles, #1 and #5. The principle behind this would be the streamline shape, and it has been previously proved that reduced resistive force from the streamline shape, and smooth surface provides farther distance of flight. However, this model has the highest kinetic energy density, and it was the only one which does not have larger tip than the minimum of allowable tip, which means it might have the potential to injury users. Therefore, the total score of performance of model #10 was downgraded.

As far, it has been perceived for the initially proposed models that those models have underprivileged accuracy rather than performance of flying distance. Consequently, it was concentrated for the further research, Part2 – Modification, to accomplish higher accuracy. To maintain the performance of flying farther, the design of #7 was elected, and the modification on that model was progressed in part2.

5.2 Part2 – Modification

5.2.1 Accuracy



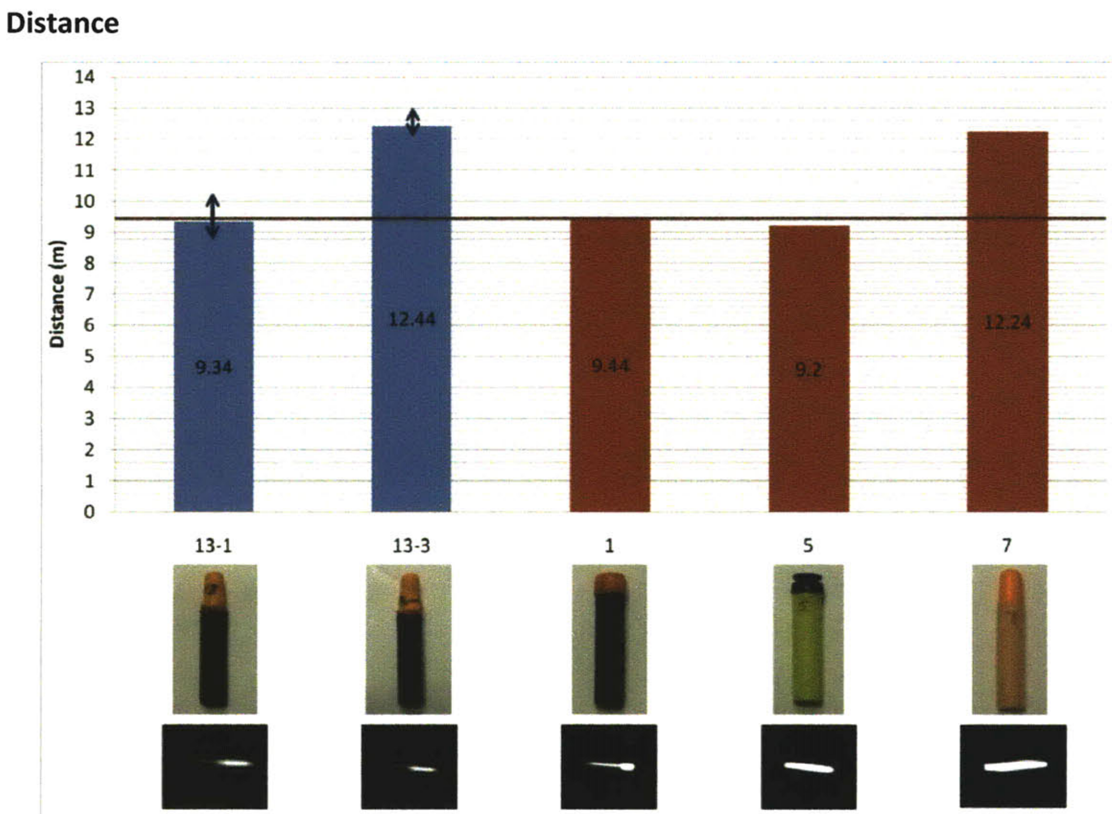
Graph 5-8 Accuracies of Modified Projectiles (Variances of Marks)

Graph5-8 demonstrates the accuracy of two modified projectile models, #13-1 and #13-3 with the state-of-the-art projectiles and model #7 which has the worst accuracy performance. The X axis shows each dart and the Y axis shows variance, Σ (distance – average distance)^2, scaled square cm. The picture of dart board presents how darts fly in similar way and direction. The larger pictures of dart boards with marks which darts made when they bump to the wall are attached in Appendix B-3. Red bars represent the accuracy data of the state of art models which have the best accuracy and the initial developed model which has the worst accuracy.

As can be seen, the modified models have much better accuracy than initially developed models, and comparable accuracy to the state-of-the-art models. The rationale behind this is that the models have unyielding pin or piece of clip to prevent the deformation of soft head. Especially, the model #13-1 has the best performance in accuracy, even 37.69% higher accuracy than model #1 which has the best accuracy in market now. The underlying principle of this is that the pin in the soft memory foam head performs its role, the preventing the deformation of head, agreeably. In addition, the washer between the head and body provides high mass for the model, and causes to fly along its own way without suffering the influence of external effects.

Prevention of soft head deformation with pin, and higher mass with washer on the same configuration of model #7 have improved the accuracy eventually.

5.2.2 Distance of flight



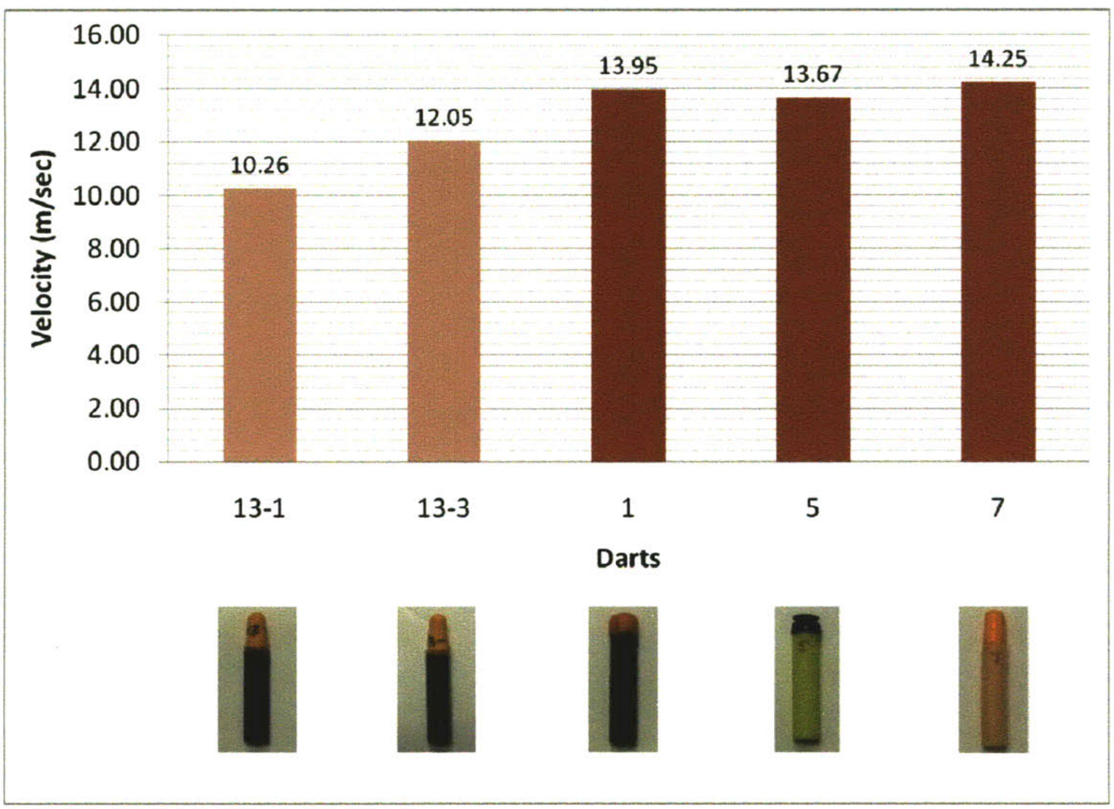
Graph 5-9 Distances of Flying Modified Projectiles

Graph 5-9 shows the distance of flight of modified projectile models with those of state-of-the-art models and model #7 which has the best performance of distance of flight. The X axis indicates each dart and the Y axis indicates the distance in meter scale. Under the X axis, the photograph of each model and snapshot of each flying model are presented. The arrow on the top of each bar graph shows variance.

As can be seen, model #13-3 fly the farthest, and it has the longer range of flight by 31.78% than the reference model #1. As mentioned in 5.1.1 the closer to streamline configuration and the low mass causes the farther distance of flight. Even thought the model #13-3 has a piece of clip, the mass of the model is still lower than those of the model #1 and/or #5. On the other hand, it seems likely that the straightness during the flight of model #13-3 provides the longer range of flight than model #7 which flies crookedly.

5.2.3 Safety

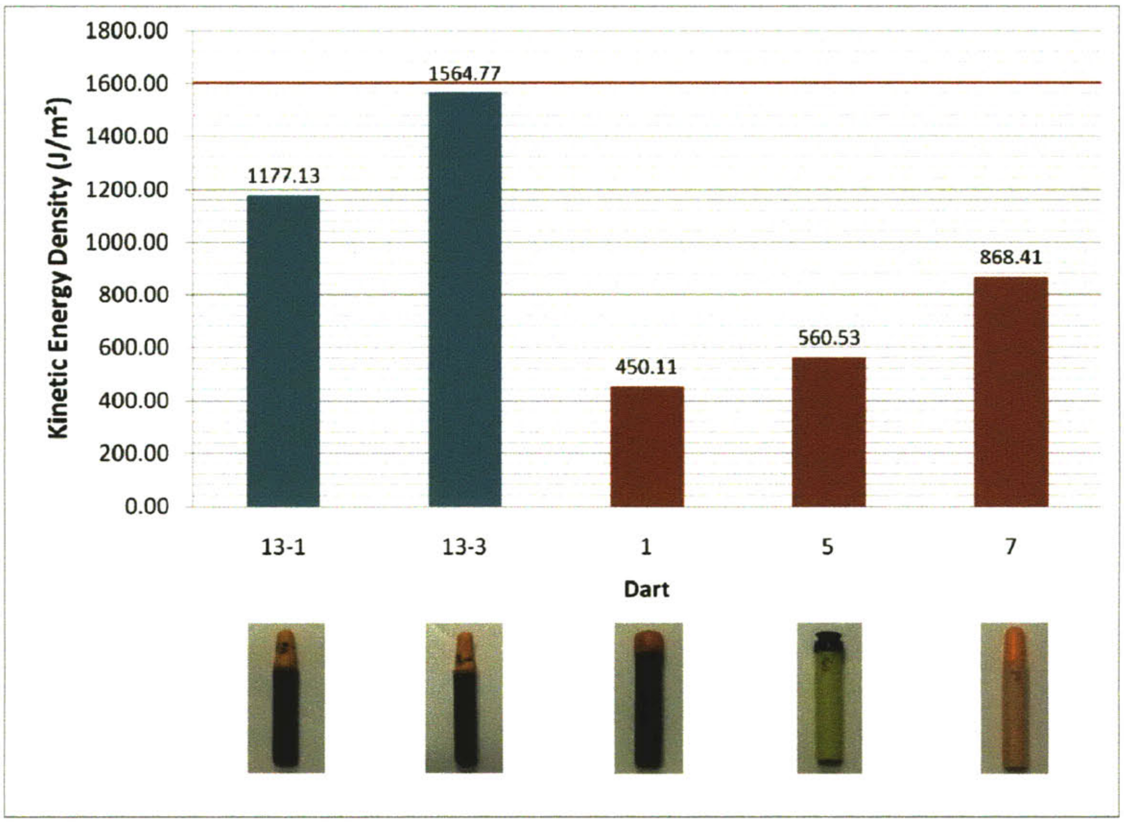
Average Velocity



Graph 5-10 Average Velocity of Flying Modified Projectiles

Graph 5-10 provides the average velocity of flying modified projectile models with those of state-of-the-art models and model #7 which has the best performance of distance of flight. The X axis shows each projectile and the Y axis shows the average velocity scaled meter per second. The arrows in the top of each bar graph show variance. As can be seen, modified model has somewhat lower average velocity than the state-of-the-art models. The model #13-1 has the lowest average velocity, and the higher mass of the model could be the reason of the result.

Kinetic Energy Density



Graph 5-11 Kinetic Energy Densities of Modified Projectiles

Graph 5-11 provides the kinetic energy densities of modified projectile models with those of state-of-the-art models and model #7 which has the best performance of distance of flight. The X axis indicates each projectile and the Y axis indicates the kinetic energy density in joule per square meter scale. As can be seen, every model does not exceed the limit kinetic energy density, 1600J/m^2, that is it complies the safety standard well.

The model #13-1 has 0.090J of kinetic energy, according to the "Corporate Quality Assurance, Safety and Reliability Specification, SRS-045, Projectiles" [3], the minimum allowable tip radius for 0.09J is 4mm, and the tip radius of the model is 4.92mm, larger than the standard. Therefore, it can be corroborated as safe projectile model. The kinetic energy of model #13-3 is 0.094J and the tip radius of the model is 4.38mm which is over the minimum allowable tip radius, so the model can be regarded as safe projectile as well.

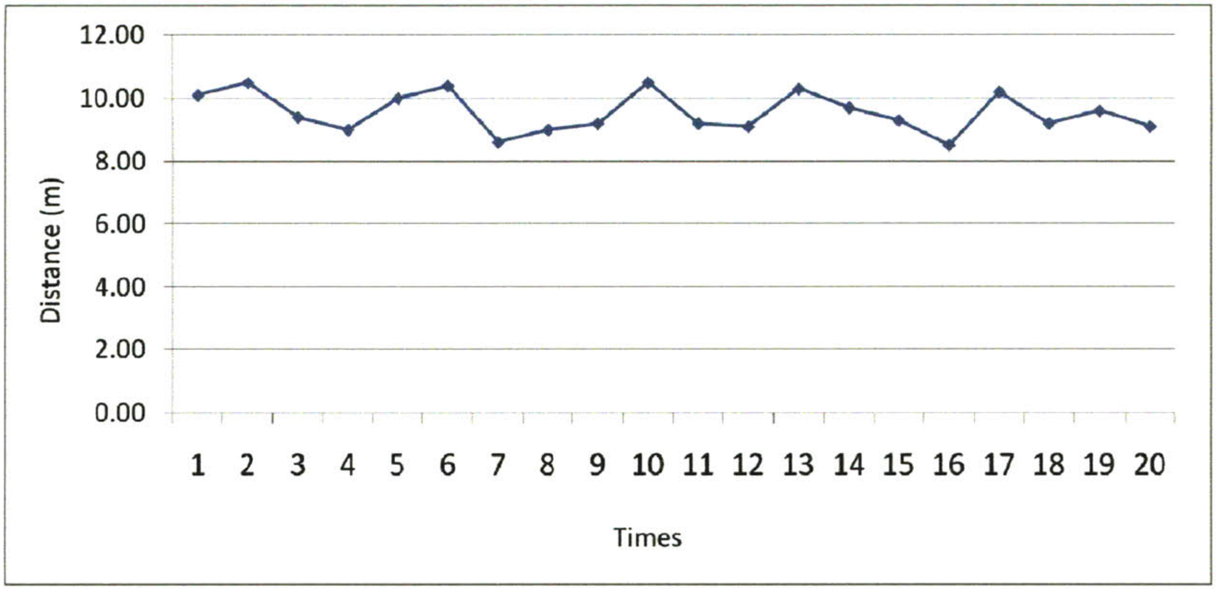
5.2.4 Total Result

	Distance	Accuracy	SUM	Rank
13-1	7.5080	-0.3077	7.20	2
13-3	10.0000	-2.1613	7.84	1
1	7.5884	0	7.09	3
5	7.3955	-0.6325	6.76	4
7	9.8392	-10.0000	-0.16	5

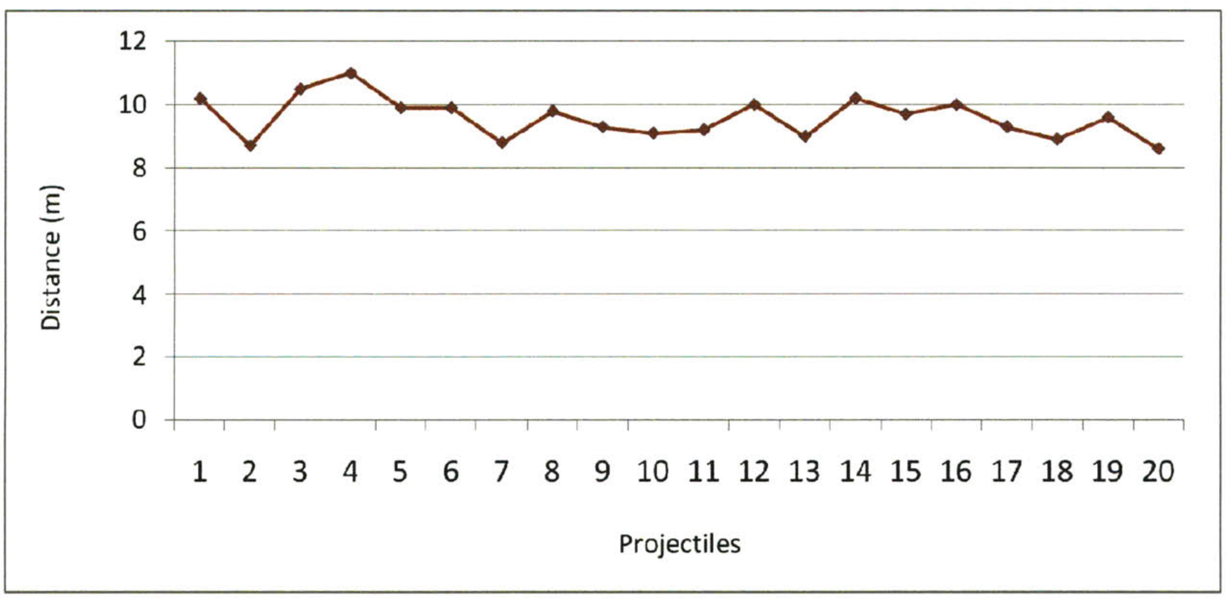
Table 5-4 Score of Each Modified Projectile Models' Performance

According to the same grading method to the 5.1.4, Table 5-4 could be provided. The safety factor of all models is proved as safe in 5.2.3, so it is excluded from the grading. Through the modification of projectile models, the ultimate improvement of performance complying with all of the objectives including distance, accuracy, and safety. The model #13-1 has the same range of flight and better accuracy than the state-of-the-art projectiles, and the model #13-3 has the longer range of flight and comparable accuracy to the state-of-the-art projectiles. Through the result, the final model could be planned.

5.3 Supplementary Evaluation



Graph 5-12 The Distances of Flying a Projectile for 20 times



Graph 5-13 The Distances of flying 20 projectiles

Graph 5-12 presents the performing error. The average distance of flying one projectile for 20 times is 9.55m and the variance of the distance data is 0.395m^2. On the other hand, Graph 5-13 shows the influence of both of production error and performing error. The average distance of flying 20 projectiles once for each is 9.59m and the variance is $0.417m^2$. As can be seen, there is no significant difference between 20 shoots of one projectile and 20 shoots of 20 projectiles, so it can be proved that the performing error mainly caused by how to install projectile influences the performance of darts more than the production error.

Chapter6

Conclusion

6.1 Final Scenarios from the Result

Scenario	Model	Distance	Accuracy	Safety
①	#7	Over 29.66% farther than the standard darts	Worse than the standard darts	Safest among the scenarios
②	#13-1	As far as the standard dart	37.69% better than the standard darts	2^{nd} safest among the scenarios
③	#13-3	Over 31.78% farther than the standard darts	Similar to the standard darts	Just under the limit
④	#7 estimated with the limit kinetic energy density	Over 45.23% farther than the standard darts	Worse than the standard darts	The limit

Table 6-1 Summary of Final Scenarios

Finally, several scenarios for better performances have obtained. Scenario ① is adopting the model #7 which flies over 29.66% farther than the standard darts #1 (Sonic Micro Dart™) and #5 (Micro Dart™) and as far as the model #10 which is almost similar to the Streamline Dart™. Then, this scenario creates worse accuracy, but the safest performance, having smallest kinetic energy density among the scenarios. Adopting model #13-1 can be a scenario ②. This scenario makes the same range of flight as the standard darts, but more than 37.69% better accuracy than standard darts and 2^{nd} smallest kinetic energy density among the scenarios. Scenario ③ with adopting model #13-3 generates over 31.78% farther distance than the standard darts, similar accuracy to the standard darts, and just under the limit of safety regulation. Because Hasbro, Inc., has been mostly interested in increasing range of flight, the scenario ④ which is adopting #7 with limit kinetic energy density can be estimated and introduced. The kinetic energy density can be increased by higher initial velocity enhancing the air-pressed force. This scenario generates more than 45.23% farther distance than the standard darts. Table 6-1 shows the summary of these scenarios.

6.2 Final Concept Sketch

Through the evaluation of flying distance, accuracy, and safety of developed models, and the analysis on the results of the evaluation enabled to approach the final model. The concepts for final models are at the following.

- The whole surface of the projectile should be smooth. There should be no bump between head and body.
- The head of the projectile should be close to streamline.
- Too high mass causing short distance of flight and high kinetic energy density, and too low mass causing unsatisfying accuracy should be prohibited. The range of preferred mass of projectile is between 0.7g and 0.9g.
- The uniform density distribution is desired for straightness of flight.
- Stiff and/or firm material such as cork which is not deformed by air pressure and flow should be installed in the head. The shape of the stiff and/or firm material should not sharp.
- The contact area should be composed with soft material to protect users from injury. The material would be memory foam.
- The occupancy of stiff material's volume in the head should not exceed 25% of the whole volume of the head.

Figure 6-1 provides one of the final concept sketches, and Figure 6-2 presents the final concept sketch refinement. The difference between those sketches is the shape design of the stiff material in the head. During refinement, the safety factor was more focused and the shape of the stiff material is altered. Even though the stiff material in the head would be cork or rubber which has no potential to injury consumers, the cylindrical figure with narrow tip of firm material which increases pressure may be harmful when the memory foam head is destroyed by numerous playing.

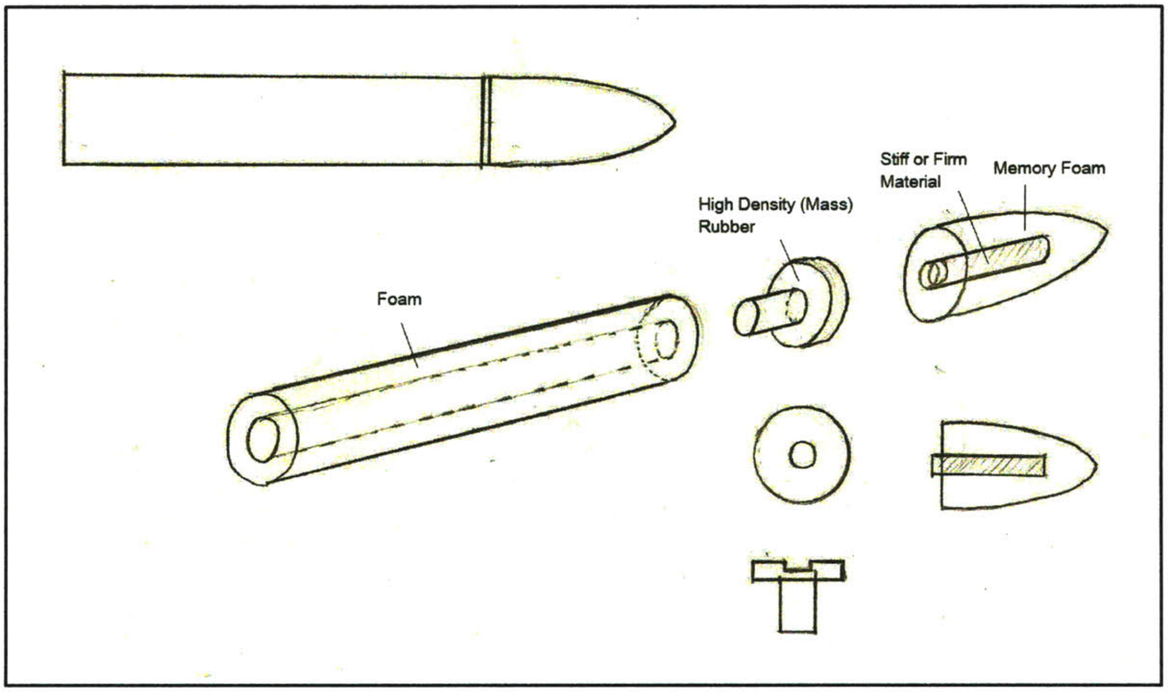


Figure 6-1 Concept Sketch

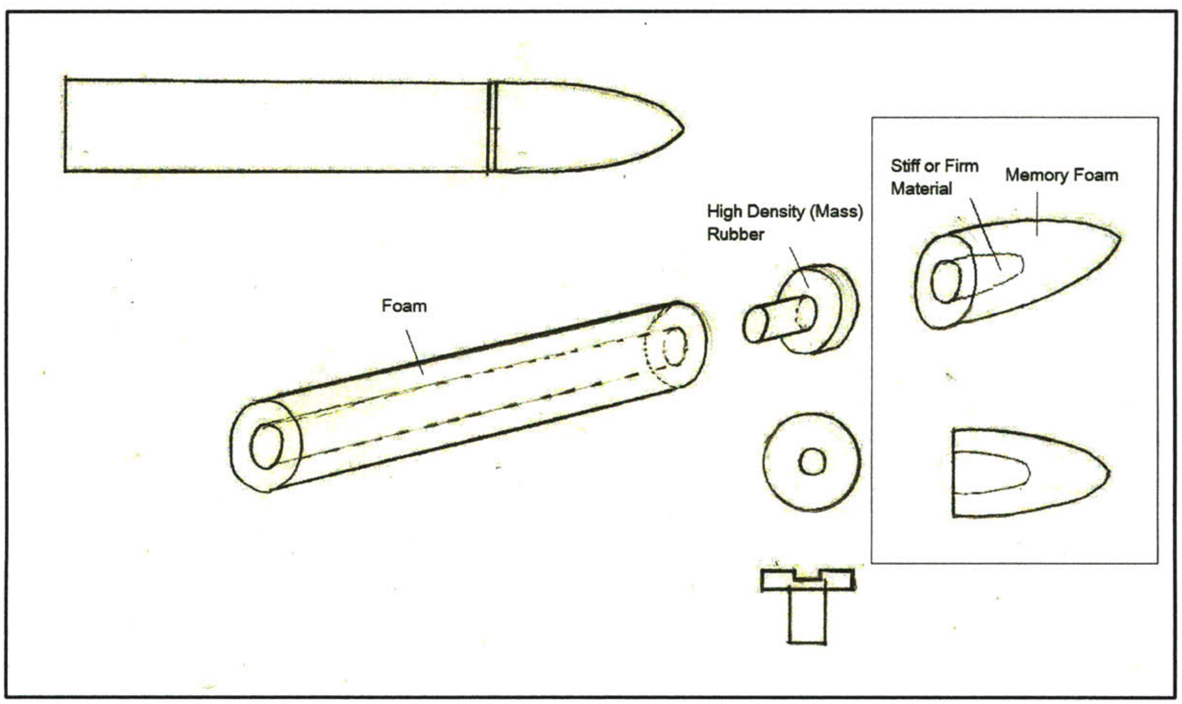


Figure 6-2 Concept Sketch Refinement

6.3 Final Model

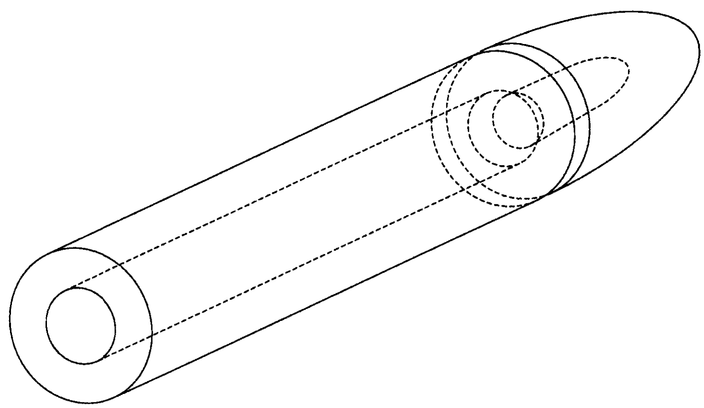


Figure 6-3 Final Model

6.4 Future Work

Figure 6-3 suggests the final CAD Model. Prototyping of the final model follow the direction described in 6.1 and evaluation tests follow the methodology presented in chapter3 will be the next step. It is confident that the performance of the final model will have better distance, accuracy, and safety because even modified model #13-1 has the same range of flight and better accuracy than the state-of-the-art projectiles, and the model #13-3 has the longer range of flight and comparable accuracy to the state-of-the-art projectiles.

Appendix A:

Corporate Quality Assurance, Safety and Reliability Specification

HASBRO INC.

CORPORATE QUALITY ASSURANCE
SAFETY AND RELIABILITY SPECIFICATION

SRS - 045
TITLE: PROJECTILES

BY: C. FISCHER
DATE: JUNE 16, 1999

APPROVAL:
REVISION: G

1.0. PURPOSE

To establish specifications for the various structural characteristics and kinetic parameters of projectiles used on Hasbro, Inc. products. The intent of these specifications is to minimize any potential for injury (especially eye injury) to children while simultaneously maintaining the traditional play value represented by projectiles at an acceptable, but under reasonably foreseeable conditions of use and abuse, safe level. Conformance to the requirements of this specification will also ensure compliance to global requirements for projectiles.

2.0. SCOPE

This specification applies to both toys A) that are intended to launch projectiles into free flight by means of a discharge mechanism in which the kinetic energy of the projectile is determined by the toy and not by the user and B) certain projectile toys without stored energy. (i.e. arrows and darts intended to be thrown, helicopter rotors, propeller blades, bows and arrows and other items intended to be thrown, but not intended to be caught).

This specification does not apply to discharge mechanisms intended to propel a ground based vehicular toy along a track or other surface, nor when a projectile is inaccessible to a child when it leaves the discharge mechanism (e.g. a pin ball machine).

Projectiles without stored energy are acceptable only for toys with a minimum age grade of 3 years and up.

Projectiles are acceptable only for toys with a minimum age grade of 4 years and up)

Projectile guns and bows and arrows are acceptable only for toys with a minimum age grade of 5 years and up.

Helicopter-type projectiles that are intended for vertical discharges are only acceptable for toys with a minimum age grade of 6 years and up.

3.0 DEFINITIONS

3.1 PROJECTILE WITH STORED ENERGY: an object propelled by means of a discharge mechanism capable of storing and releasing energy under the control of the operator.

3.2 PROJECTILE WITHOUT STORED ENERGY: An object propelled solely by the energy imparted by a child.

3.3 DISCHARGE MECHANISM: an inanimate system for releasing and propelling projectiles.

3.4 PROJECTILE TIP - Any portion of a projectile that can reasonably be expected to contact an impact surface (e.g. an eye) during flight. A tip end or leading edge of a projectile is not the only possible "tip". On disc or saucer like projectiles, the "edge" of the disc is considered as the tip. On rotor-type projectiles that have a ring around the perimeter, all exposed surfaces of the ring should be considered "tips".

Note: The requirements of 6.3 apply to all "tips".

See Figure 2 for a pictorial depiction of the proper radii on a disc-type projectile.

3.5 PROTECTIVE TIP: - a component that is attached to the impacting end of a projectile to minimize injury if it should impact on the body and also to prevent damage to the projectile on striking a target, or prevent damage to inanimate objects.

3.6 RESILIENT TIP: a tip on impact surface of a projectile that has a Shore A durometer not greater than 55 (as measured on the impact surface of the tip).

3.7 RIGID PROJECTILES: projectiles with an impact tip that has a shore A durometer that is greater than 55.

3.8 PROJECTILE GUNS AND BOWS AND ARROWS: are hand-held projectile launchers that are comparable in scale to a real firearm or bow and arrow. For purposes of this specification, small projectile launchers scaled to the size of toy figures (e.g. G.I. Joe) are not "projectile guns".

4.0. TEST EQUIPMENT

4.1 A radar gun capable of measuring a small projectile (larger than Hasbro small part gage) traveling at a high speed (e.g. 11 miles/hour).

4.2 Hasbro small parts cylinder (per SRS-001, figure 2).

4.3 Laboratory balance with an accuracy of +/- 0.1 gram. (i.e. Sauter K800).

4.4 Aluminum foil complying with the requirements of 5.2.

4.5 A steel ball having a nominal diameter of 15 mm and a mass of 14.00 +/- 0.05 grams.

4.6 Clamps to uniformly clamp the diaphragm in the supporting frame - See Figure 1.

5.0 TEST PROCEDURE

5.1 KINETIC ENERGY DETERMINATION

5.1.1 The kinetic energy (in joules, j) of a projectile shall be determined from the following equation:

kinetic energy = 1/2 mv^2
where: m = mass of projectile (Kg) and,
v = velocity of the projectile (meter/sec.)
Conversion factor: Meters/sec = .447142 x miles/hour

5.1.2 The mass of projectile (kg) shall be determined by weighing a sample on a laboratory balance. A sufficient sample size (at least 30) of projectiles shall be weighed to determine the average weight plus 3 standard deviations. This upper limit weight in

Kg is used for "m".

5.1.3 The velocity of a projectile (v) shall be determined by firing a sample from the discharge mechanism of the toy projected out in front of the radar gun. Recording m.p.h.). The velocity of the projectile shall be calculated from the expression

v (meters/seconds) = mph x .447142. The value of v in the equation is the average of five measurements of a given projectile.

5.2 Test for Penetration of Toy Projectiles with Stored Energy

5.2.1 Foil

From a roll of aluminum foil, cut out twenty samples measuring 105 mm x 105 mm. Ensure that each sample is free from obvious imperfections including creases or wrinkles. Ten samples of aluminum foil are required to verify the quality of the aluminum foil and ten samples are required to test the toy.

5.2.2 Foil Verification.

a) The quality of the foil should be verified as follows:

b) Place one of the samples of foil between the two O-rings of the clamping frame and clamp the foil between the clamps so that the foil diaphragm is evenly tensioned with no creases or wrinkles.

c) Place the clamping frame on a substantially horizontal surface so that the foil diaphragm makes an angle between 15 degrees and 20 degrees relative to the horizontal.

d) Position the steel ball so that when the ball is released, it would fall freely through a vertical distance of 300 mm to strike the central 25 mm diameter area of the foil diaphragm.

e) Examine whether or not the foil diaphragm ruptured, as specified in 5.2.3

f) If the steel ball does not cause the foil diaphragm to rupture, repeat steps b) to d) a further four times, provided that each time the foil diaphragm does not rupture.

g) If all five of the foil diaphragms do not rupture, repeat steps b) to d), but this time, drop the steel ball through a height of 500 mm.

h) If the ball causes the foil diaphragm to rupture, as specified in 5.2.3, repeat steps b) to d) a further four times, provided that each time the foil diaphragm does rupture.

5.2.3 Interpretation

The foil diaphragm shall be considered as not ruptured if the foil shows, without magnification, no split or hole. A mere dent shall not be considered as a rupture.

The foil diaphragm shall be considered as ruptured if the foils shows, without magnification, a split or hole.

The ten remaining foil samples that are to be used to test the toy shall be considered as verified as being of a suitable quality if all five samples that were subjected to the ball drop height of 500 mm did rupture.

5.2.4 Test Specimen

The toy submitted for this test shall be representative of the normal population and shall not have been subjected to any normal use and reasonably foreseeable abuse tests prior to penetration testing the toy.

5.2.5 Procedure

The procedure shall be carried out in a conditional environment as follows:

a) Place one of the verified foil samples between the two O-rings of the clamping frame and clamp the foil using the clamps so that the foil diaphragm is evenly tensioned with no crease or wrinkles.

b) Place the clamping frame such that the foil diaphragm lies in a substantially vertical plane.

c) Load the projectile into the discharge mechanism.

d) Position the toy so that:

1) The end of the toy, that is, the end of the projectile or the end of the discharge mechanism whichever protrudes furthest, is 150 mm from the foil diaphragm; and

2) When the projectile is ejected, the flight path of the projectile would be substantially normal relative to the foil diaphragm and the projectile would strike the foil's center as possible.

e) Eject the projectile.

f) Observe whether or not the projectile ruptures the foil diaphragm as specified in 5.2.3.

g) Repeat steps a) to f) a further nine times using the other nine verified foil samples.

5.2.6 Report

The report shall state the number of times the projectile ruptured the foil diaphragm when the toy was tested in accordance with 5.2.5.

5.3 Impact Test For Projectiles

Projectiles shall be propelled by their discharge mechanism six times into a concrete block wall (or equivalent surface) located at a distance 1 foot (300 mm) plus the length of the projectile from the front end of the discharge mechanism. The discharge mechanism shall be aimed perpendicular to the wall.

5.4 Use and Abuse Testing

Perform all pertinent use, abuse, life, and environmental testing on the projectile per the appropriate test plan for its parent product.

5.5 Improvised Projectile Test

Determine through experimentation if discharge mechanism is capable of discharging projectiles other than the projectile specifically designed for use with the discharge mechanism. Testing of improvised projectiles shall include, but is not limited to, the following objects:

<u>DIMENSIONS OF IMPROVISED PROJECTILES</u>

(All measurements in inches)

A) Correction Pen Cap

1) Pentel Opaquing Fluid Correction Pen
Oil-Based Quick Dry
18 ml. ZLC1-W
Manufacturer: Pentel Co. Ltd.
Made in Japan

Dimensions

A1) total length-1.10 inches
maximum diameter - 0.57 inch
minimum diameter - .53 inch

B) Marker

1) Pentel Marker
F50
Made in Japan

Dimensions

B1) total length - 3.3 inches
diameter - 0.91 inch

Tip: length - 0.28; width-0.18 inch
Tip Body: length - 0.70 inch
max. diameter-0.65 inch
min. diameter-0.36 inch

C) Marker Caps

1) Fluorescent Pen Cap
Zebra Pen 2
Thin Size Cap

2) Fluorescent Pen Cap
Zebra Pen 2
Thin Size Cap

3) Fiber Tip Permanent Marker Cap
Artline 70 High Performance
Xylene Free EK-70
Manufacturer: Shachihata Product
Made in Japan

4) Fiber Tip Permanent Marker Cap
Artline 70 High Performance
Xylene Free EK-700
Manufacturer: Shachihata Product
Made in Japan

Dimensions

C1) length - 0.93 inch
max. diameter - 0.35 inch
min. diameter - 0.23 inch

C2) length - 1.82 inches
max. diameter - 0.58 inch
min. diameter - 0.28 inch

C3) length - 1.71 inches
max. diameter - 0.66 inch
min. diameter - 0.51 inch

C4) length - 1.52 inches
max. diameter - 0.70 inch
min. diameter - 0.69 inch

D) Paper Clip	Dimensions
1) Trigonal Clip # Elephant Trigonal Art. No. PM121 Made in China	D1) length - 1.19 inches max. diameter - 0.37 inch min. diameter - 0.15 diameter of wire - 0.04 inch
E) Pen	Dimensions
1) Ball Pen Body Zebra - New Crystal N-5000 Made in Japan	E1) length - 4.56 inches max. diameter - 0.32 inch min. diameter - 0.200 inch
2) Ball Pen Body Zebra - Hard-Crystal N-5100 Made in Japan	E2) length - 4.83 inches max. diameter - 0.31 inch min. diameter - 0.21 inch
3) Ball Pen Body Bic #C-B-19	E3) length - 5.32 inches max. diameter - 0.29 inch min. diameter - 0.24 inch
4) Ball Pen Cap Zebra N-5000 Made in Japan	E4) length - 2.32 inches max. diameter - 0.47 inch min. diameter - 0.25 inch
5) Ball Pen Metal Nozzle Zebra - Hard Crystal N-5100	E5) length - 0.46 inch max. diameter - 0.22 inch min. diameter - 0.13 inch
F) Pen Refill	Dimensions
1) Bic #C-B-19	F1) length - 5.17 inches max. diameter - 0.19 inch min. diameter - 0.12 inch
2) Zebra Ballpoint Pen Refill BR-6A-H-BK	F2) length 5.48 inches max. diameter - 0.12 inch min. diameter - 0.09 inch

G) Battery	Dimensions
1) "Energizer" AA	G1) length - 1.74 inches diameter - 0.41 inch
2) "Energizer" AAA	G2) length - 1.97 length diameter - 0.52 inch
3) "Energizer" C Size	G3) length - 1.95 inches diameter - 0.99 inch
H) Marble & Pebble	Dimensions
1) Diameter 1"	H1) diameter - 1 inch
2) Diameter 0.635"	H2) diameter - 0.635 inch
3) Diameter 0.642"	H3) diameter - 0.642

Hazard evaluation of launched improvised projectiles shall include (but is not limited to) the following: Tip radii relative to kinetic energy; for rigid projectiles, the kinetic energy; for non-rigid or resilient tipped projectiles; the kinetic energy density.

5.6 Projectile Configuration Evaluation

Projectiles must not have projections (i.e. ribs, missiles, fins, etc.) that protrude from the main body of the projectile and have the potential to generate a "fishhook" effect. Generally, projections that extend 3/16" or more from the body of the projectile and subtend an angle of 30-90 degrees from the body and are not "blended" to the body will be considered as having the potential to generate a "fishhook" effect and are not acceptable for use on the Hasbro, Inc., products. However, projectiles of a size and/or shape such that they don't penetrate to the full depth of the Hasbro Supplemental Test Fixture (see SRS-004, Figure 2) in their normal flight orientation shall be considered acceptable regardless of configuration. The configuration of all projectiles must be approved by Quality Assurance.

5.7 Unexpected Discharging Of Projectiles

Determine through experimentation if the discharge mechanism is capable of discharging projectiles in an unforeseeable, unexpected, or inordinately delayed fashion. When the projectile is in its normal launching position only the activating button, lever or switch must be capable of discharging the projectile. The actions and movements of the toy during all of its reasonably foreseeable normal play modes must not activate the discharge mechanism.

Also, reasonably foreseeable and normally expected handling or carrying the toy must not activate the discharge mechanism. In addition, the projectile should discharge within a reasonable time period after activation. (see 6.8)

5.8 Projectile Kinetic Energy Density

The projectile kinetic energy density must be determined on all projectiles with a kinetic energy greater than .08joule. The Projectile Kinetic Energy Density is the kinetic energy of the projectile divided by its contact area. On non-rigid (i.e. including resilient tipped) projectiles the contact area is measured by applying a suitable staining agent (e.g. Prussian Blue) to the projectile, firing it at a suitable surface 1 foot away and measuring the area of the residual impression. Area is determined by the following:

Radius in meters: Area = Πr^2
Radius in inches: Area = $.0006452 \Pi r^2$

The kinetic energy density is expressed as joules/area.

5.9 Arrows, Darts and Other "Thrown" Items and Bows

The kinetic energy of arrows, darts and other projectiles intended to be thrown shall be imparted to the projectile by a adult throwing the projectile with the highest reasonably foreseeable velocity. To determine the highest reasonably foreseeable velocity, child testing with children of the highest age for which the toy is intended may be required.

For bows, use an arrow intended for the bow and stretch the bow string, using a maximum force of 8.0 lbs. (35.6 newton), as far as the arrow allows, but to a 28 inch maximum (71 cm).

6.0 SPECIFICATIONS

6.1 No projectile intended to be fired from the toy shall have sharp edges per SRS-003, sharp points per SRS-002, or parts that fit without compression (i.e. the 1 lb. weight is NOT used) into the Hasbro cylinder per SRS-001. (NOTE: pieces that detach as a result of abuse test and cannot be launched by the discharge mechanism are not projectiles).

6.2 No projectile shall have a configuration that generates a "fishhook" effect. (See 5.6).

6.3 No projectile fired from a toy shall have a tip radius less than 2 mm (.08 in.). The minimum allowable tip radius increases in direct proportion to the kinetic energy of the projectile per the table below:

PROJECTILE ENERGY LEVEL	MINIMUM ALLOWABLE TIP RADIUS
up to .025 joule	2 mm
from .025 to .05 joule	3 mm
from .05 to .10 joule	4 mm
from .10 to .15 joule	5 mm
from .15 to .20 joule	6 mm

NOTE: Any projectile with an energy level of .25 joule or greater must be reviewed and approved by Senior Vice President, Hasbro Quality Assurance.

Projectiles in the form of arrows or darts or other missile-shaped objects that are intended to be thrown by the user must have resilient tips with an impact area of at least 4 cm^2. (.620 in^2)

Helicopter rotors and single propellers intended to be powered into vertical or nearly vertical flight by a spring mechanism or similar device must have a ring around the perimeter that complies with all the radii requirements of this section.

6.4 Any projectile fired from the toy that has a kinetic energy that exceeds .08 joule (as determined by section 5.1) shall have an impact surface (s) of a resilient material.

NOTE: If the flight characteristics of the projectile are such that it tumbles or turns around in flight when the kinetic energy exceeds .08 joule, then all profile surfaces are to be treated as impact surfaces.

6.5 Discharge mechanisms must be unable to discharge hazardous improvised projectiles.

6.6 All projectiles must withstand the impact test for projectiles (5.3 above) without the generation of a hazardous condition.

6.7 A protective tip shall not be detached from the projectile when subjected to torque/tension test per SRS-006 (i.e. 8 in-lbs torque/20.5 lbs tension) and shall not detach or produce or reveal hazardous points or edges when fired into a solid object according to test procedure described in 5.3 above.

6.8 Projectiles must not be discharged in an unexpected fashion. Projectiles must discharge within 4 seconds after launch activation (unless there is ample warning in the form of lights, sounds, etc.)

6.9 The Kinetic Energy Density of projectiles must not exceed 1600 joules/m . (See section 5.8).

NOTE: Kinetic Energy Density determination is not required for projectiles with an energy level less than .08 joule.

6.10 A toy, when tested in accordance with 5.2, shall not eject a stored energy projectile that results in the rupturing of more than two out of the ten foil diaphragms.

6.11 Any subject toy capable of discharging a projectile with a kinetic energy greater than 0.08 joule must carry a cautionary statement on the toy (see SRS-070 - Section 4.8).

6.12 All projectiles must meet above specifications both before and after all pertinent use, abuse, life and environmental testing per the appropriate test plan.

6.13 Summary of Selected Requirements

Projectile Type	Tip Radii (Section 6.3)	Resilient Tip* (6.4)	K.E.D. (6.9)	Foil Test (6.10)
Rigid	Yes	Yes	No	Yes**
Stored energy	Yes	Yes	Yes*	Yes**
No stored energy	Yes	Yes	Yes*	No

*Applies only if K.E. is > .08 joule
**Does not apply to disc or saucer type projectiles.

7.0 REFERENCES

7.1 F963 (ASTM), sections 4.20 and 8.15

7.2 Product Safety and Liability Reporter, 8/21/81, pp 645-646

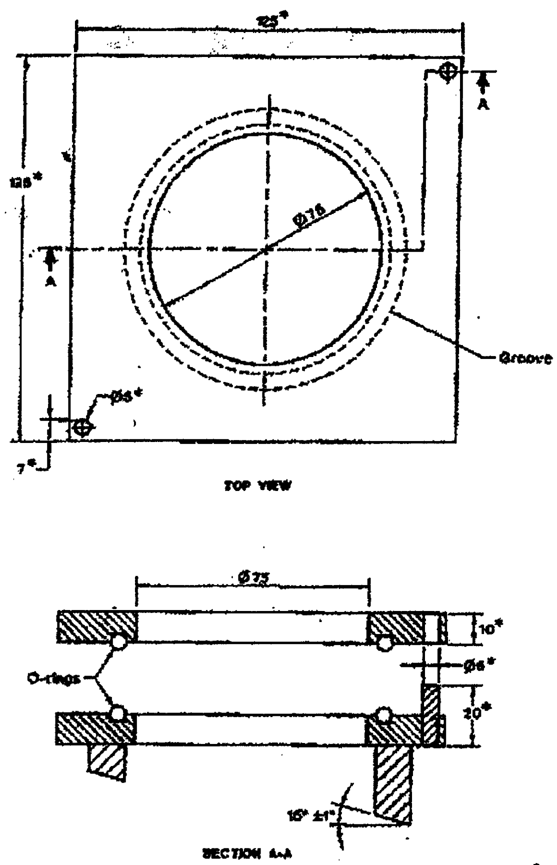
7.3 NBS report No. 10-893 "Ocular injury potential of projectile-type toys, 8/1/72

7.4 EN71-1: 1998, Sections 4.17 and 8.25

7.5 "Guidelines for relating children's ages to toy characteristics", CPSC, 10/7/85, Page 181.

7.6 Australian Standard 1647.2-1992, "Children's Toys (Safety Requirements), Constructional Requirements", Section 7.15, Appendix K and Appendix DD.

SRS-045



NOTES:
1 The dimensions marked * shall be within a tolerance of ±1 mm.
2 The dimensions not marked * shall be within a tolerance of ±0.2 mm.

REVG

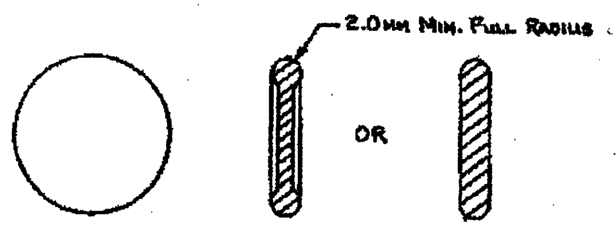
DIMENSIONS IN MILLIMETRES

FIGURE 1

FIGURE DD1 PLAN VIEW OF CLAMPING FRAME

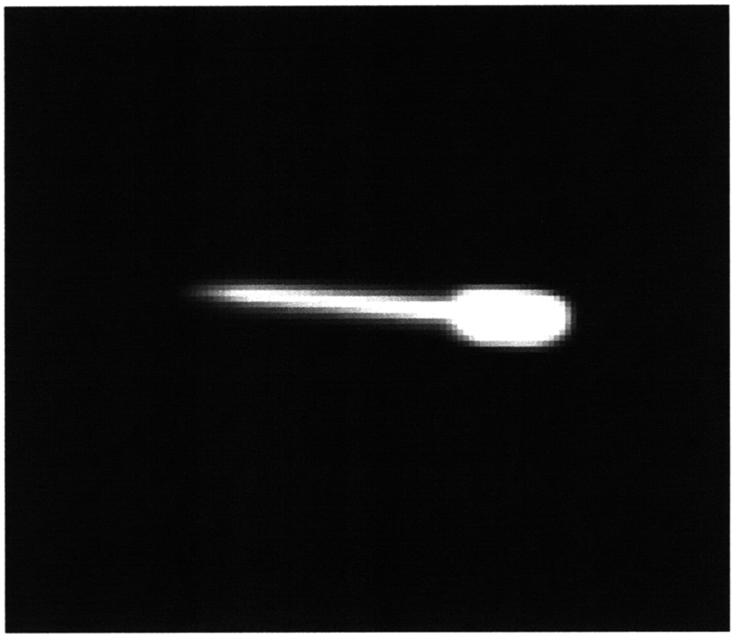
SRS-045
REV G
Figure 2

Disk Projectiles

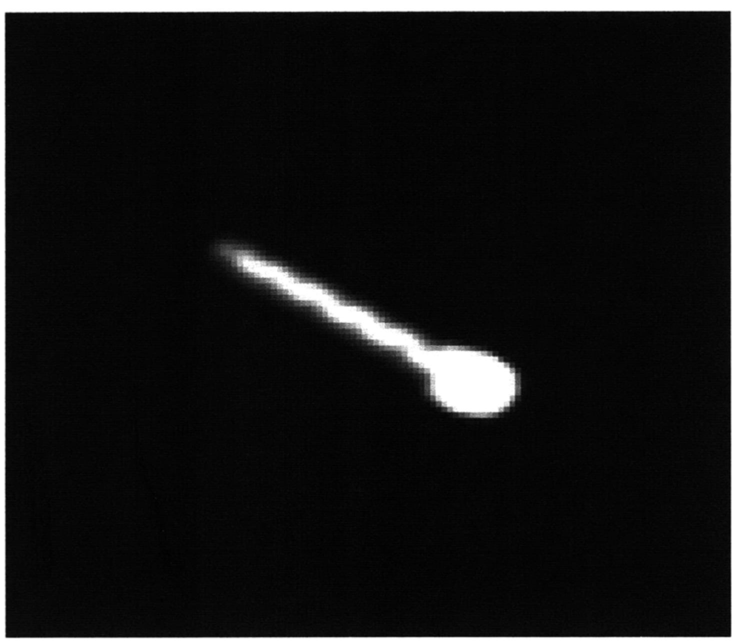


Appendix B: Image

B-1 Snapshot of High Speed Imaging



Snapshot of Model #1



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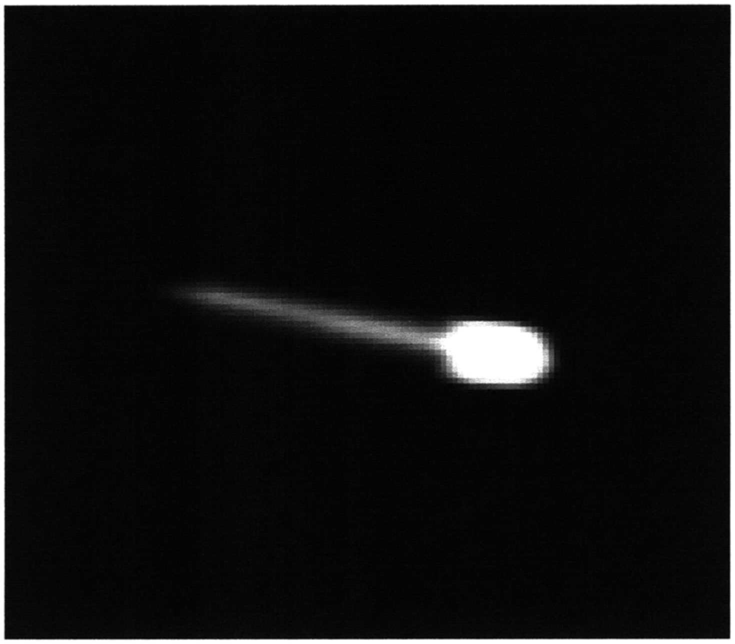

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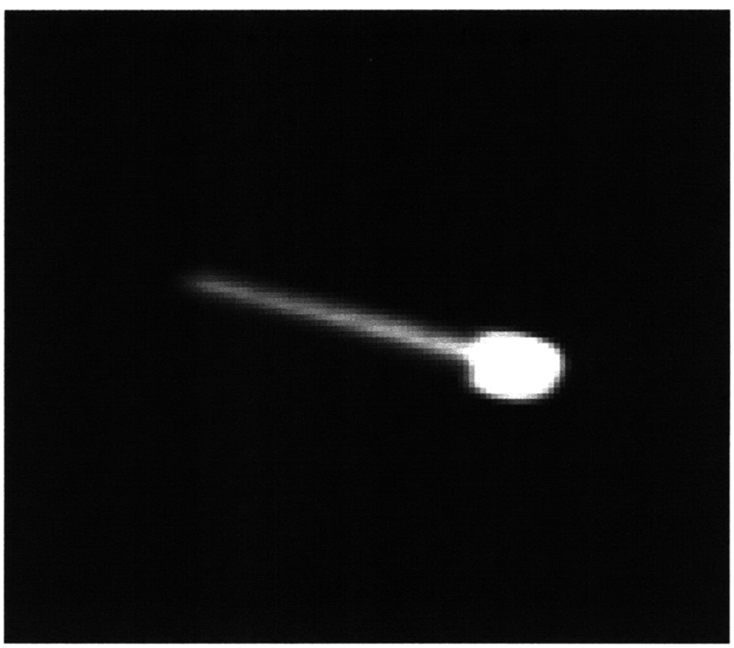

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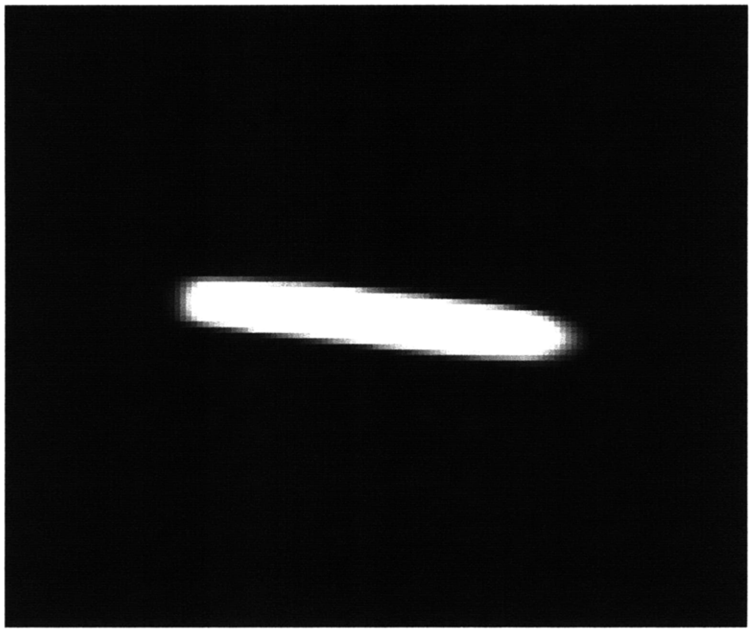
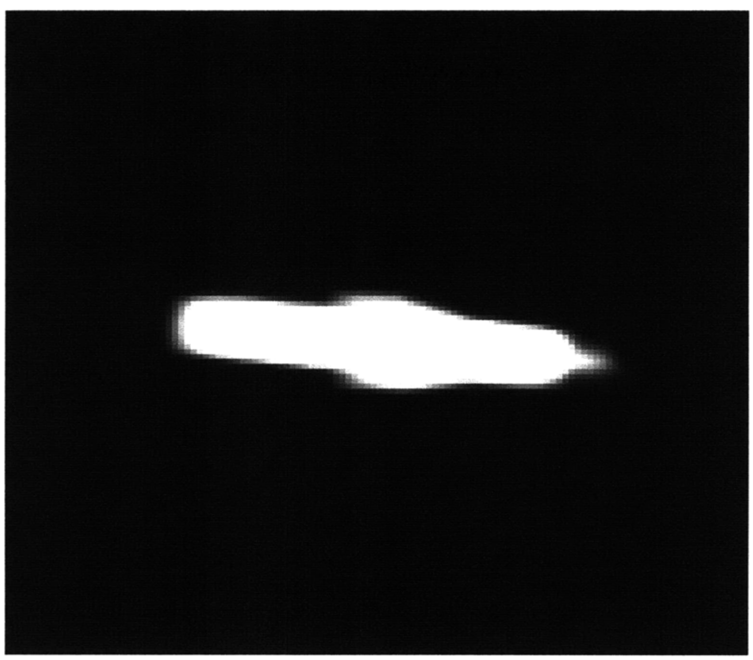
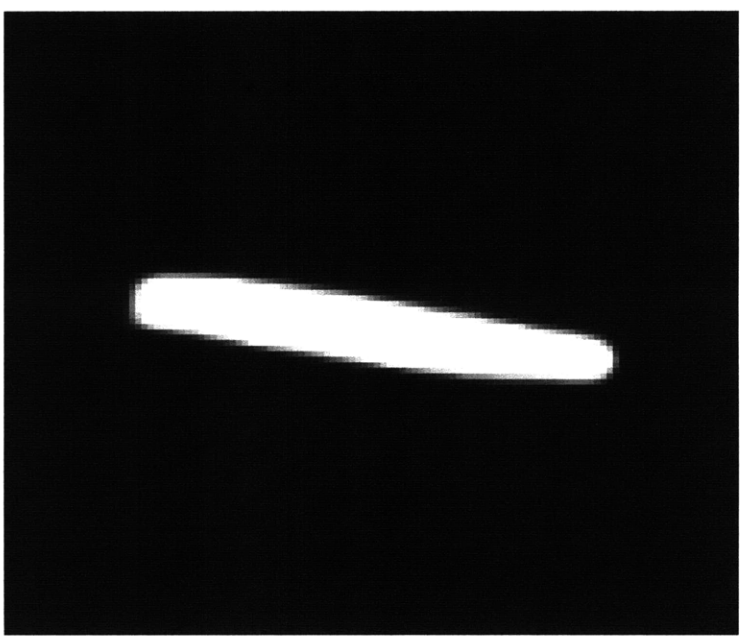


Snapshot of Model #5

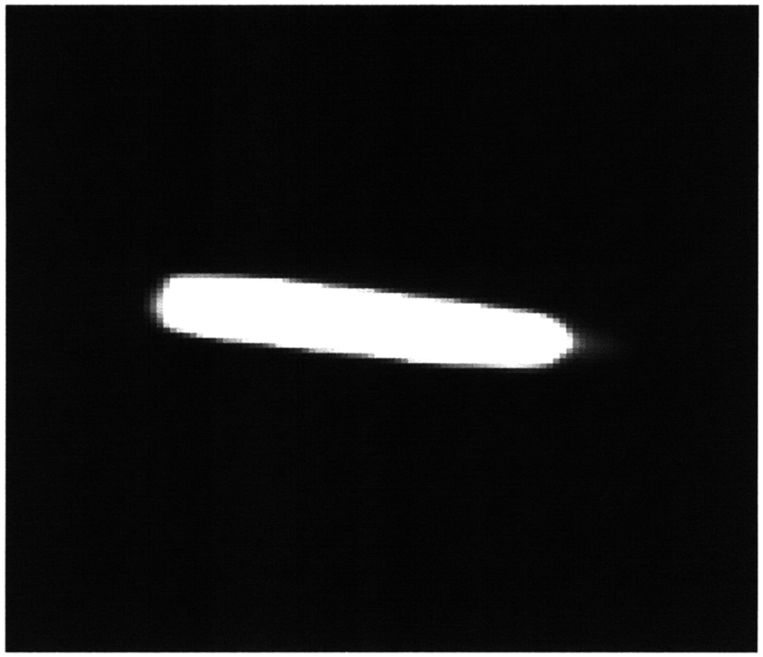


Snapshot of Model#6

Snapshot of Model #7



Snapshot of Mode #8



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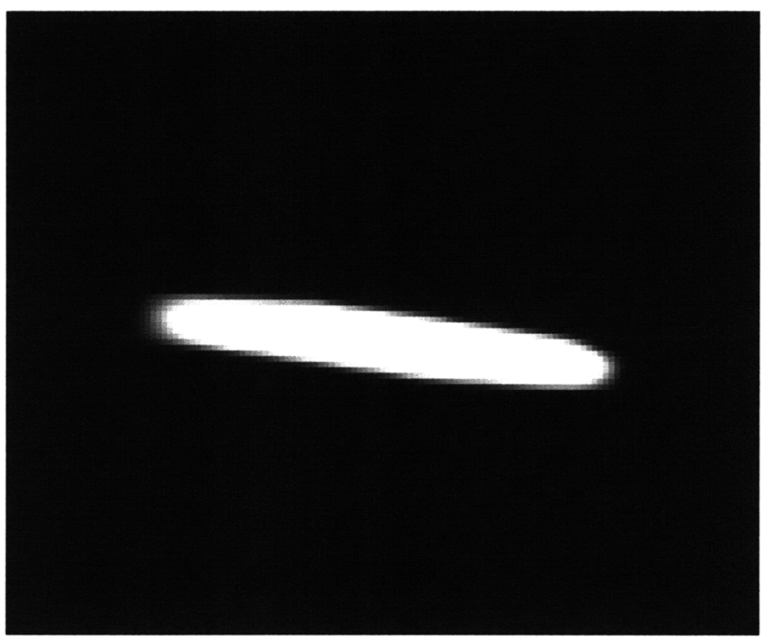

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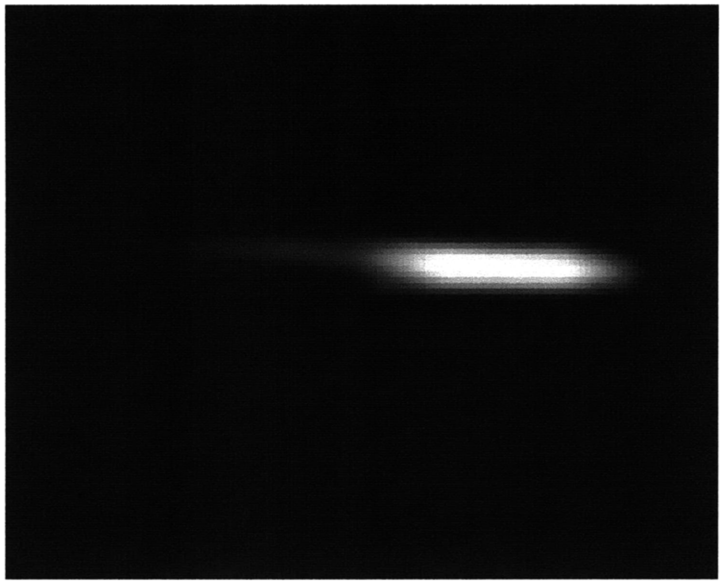
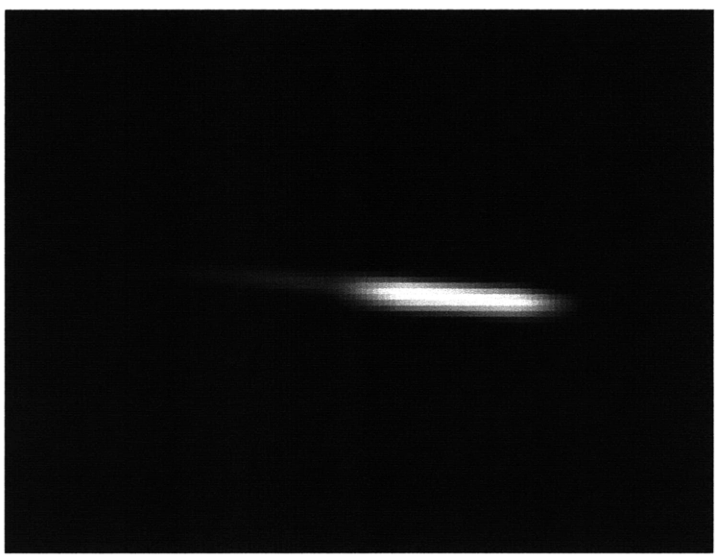


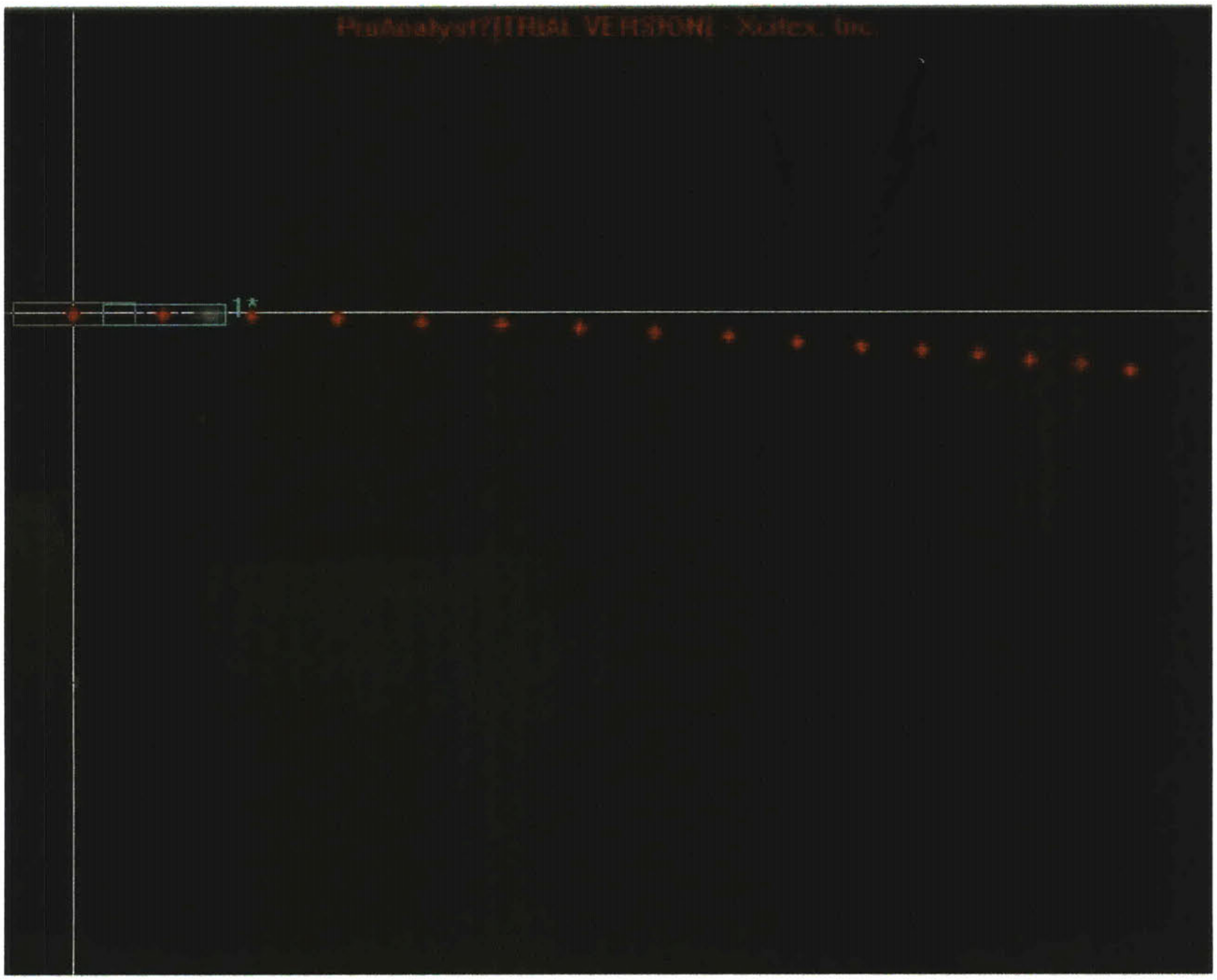
Snapshot of Model #13-1



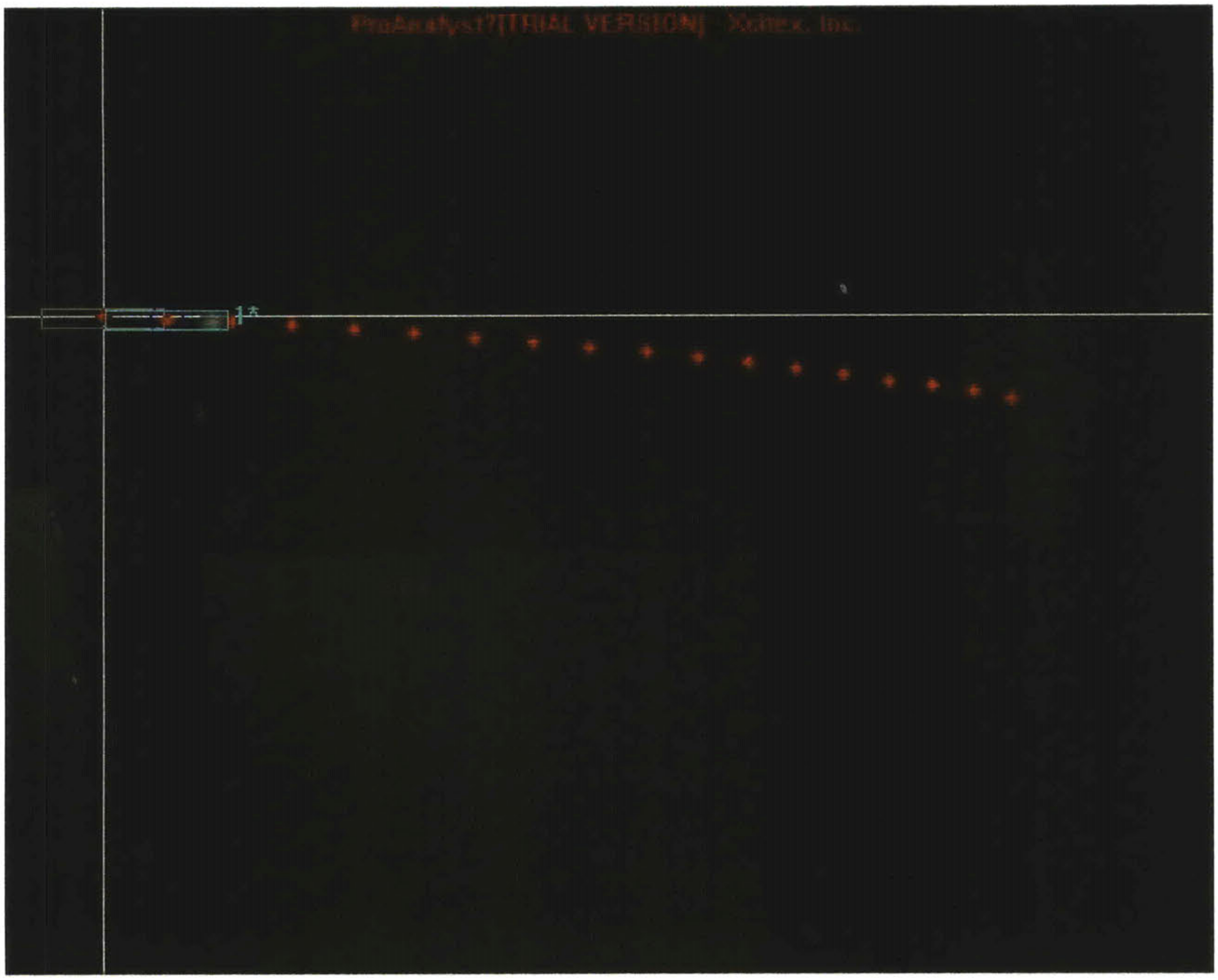
Snapshot of Model #13-3

Appendix B: Image

B-2 Trajectory of Projectile



Trajectory of Model #1



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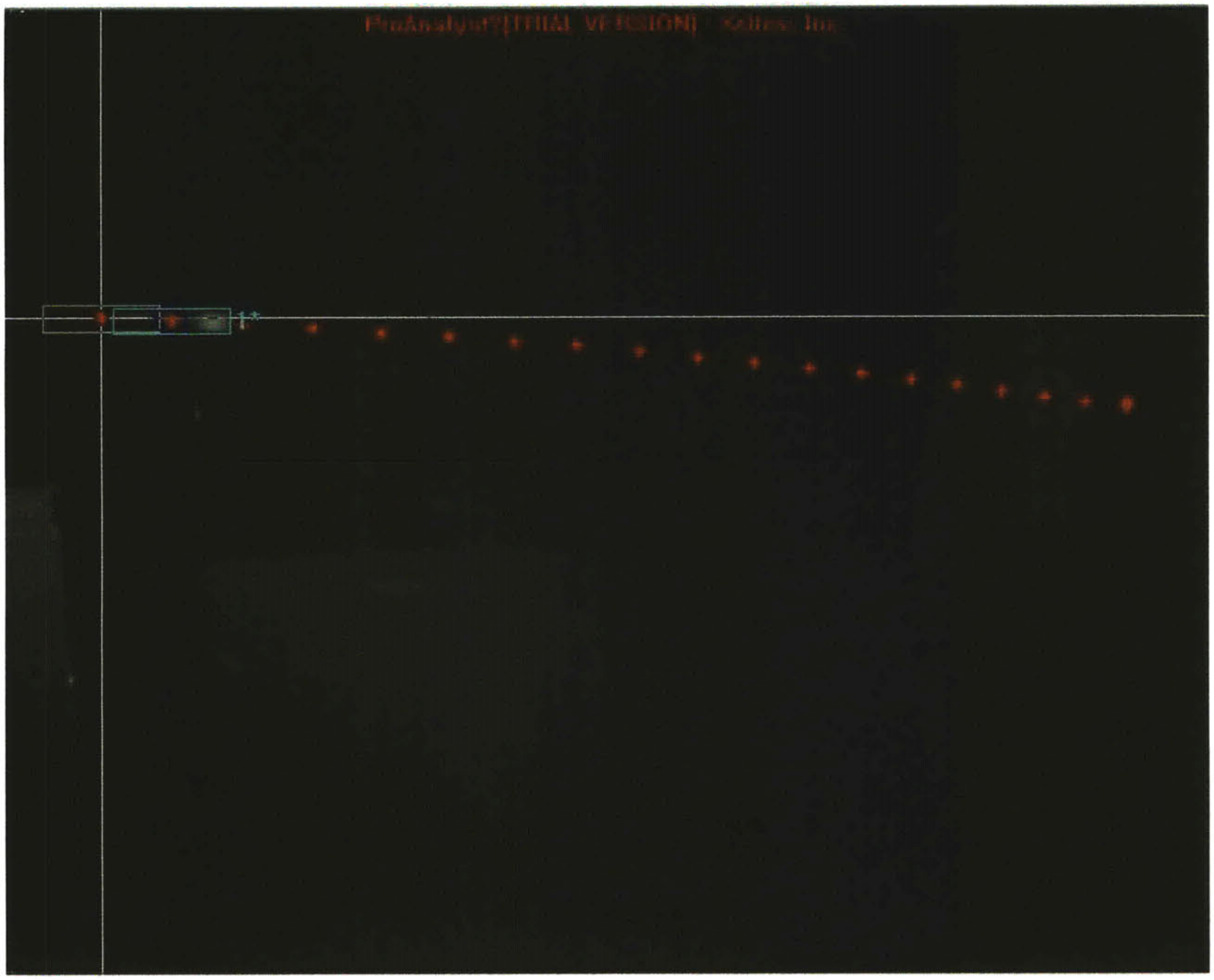
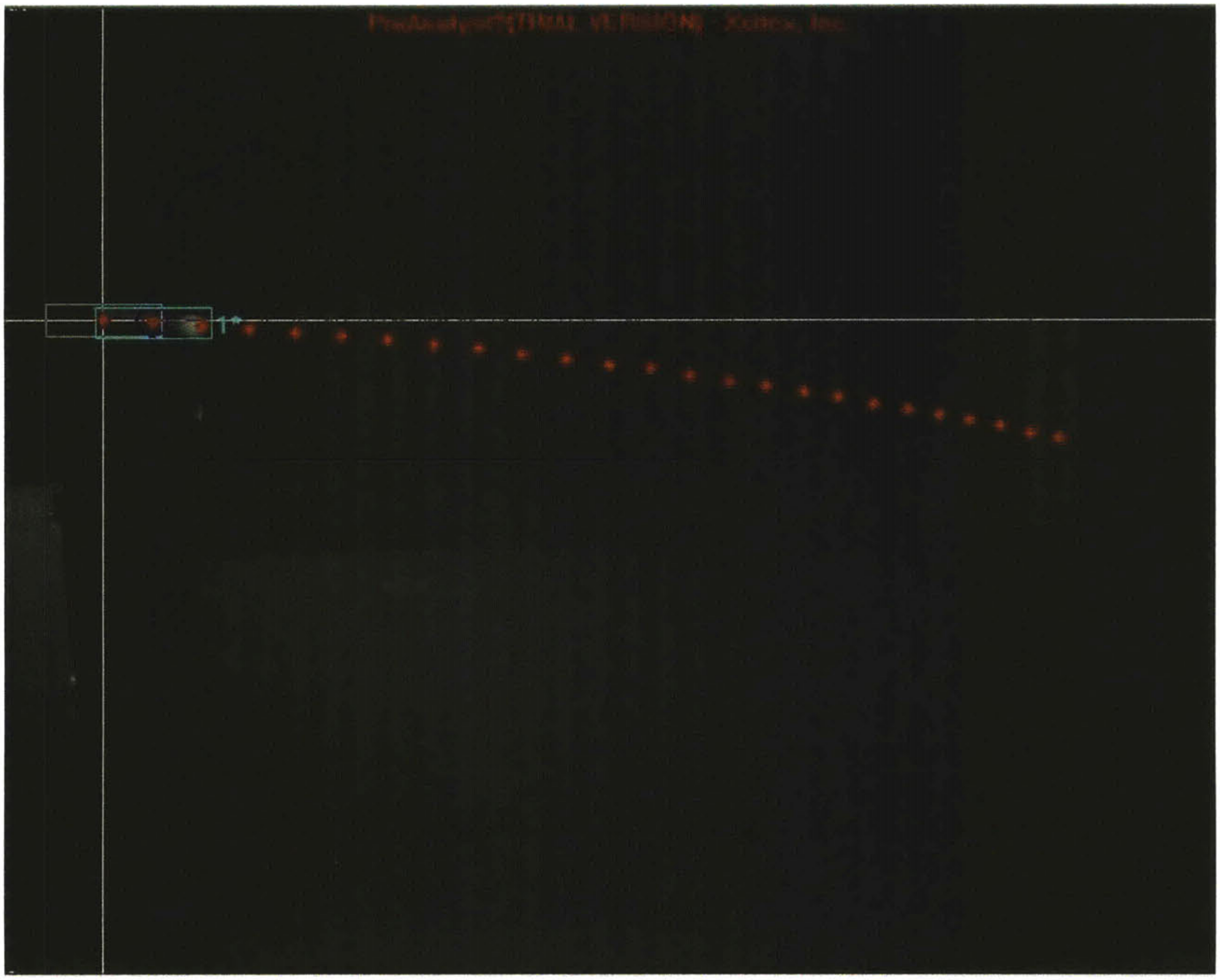
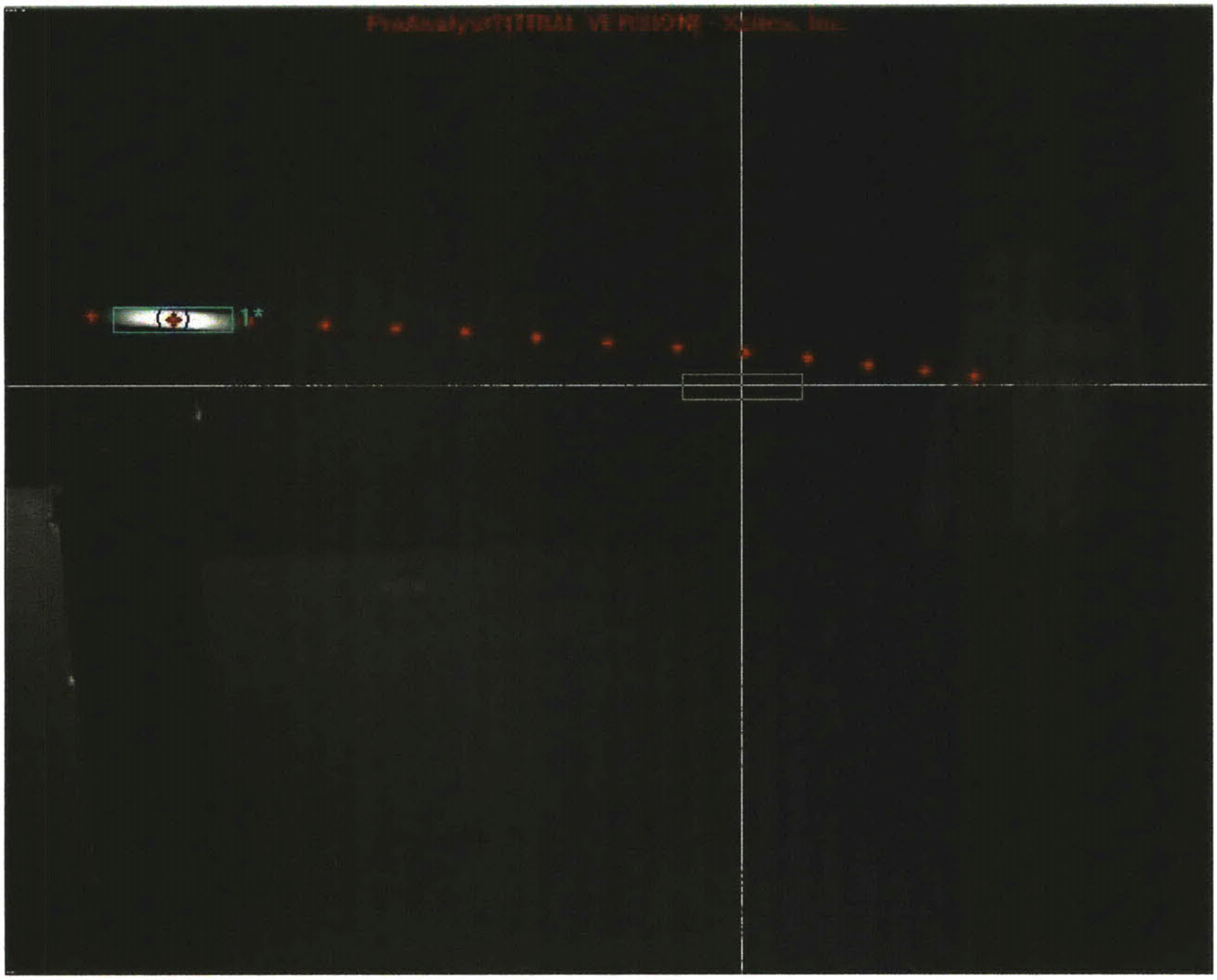


Trajectory of Model #3



Trajectory of Model #4



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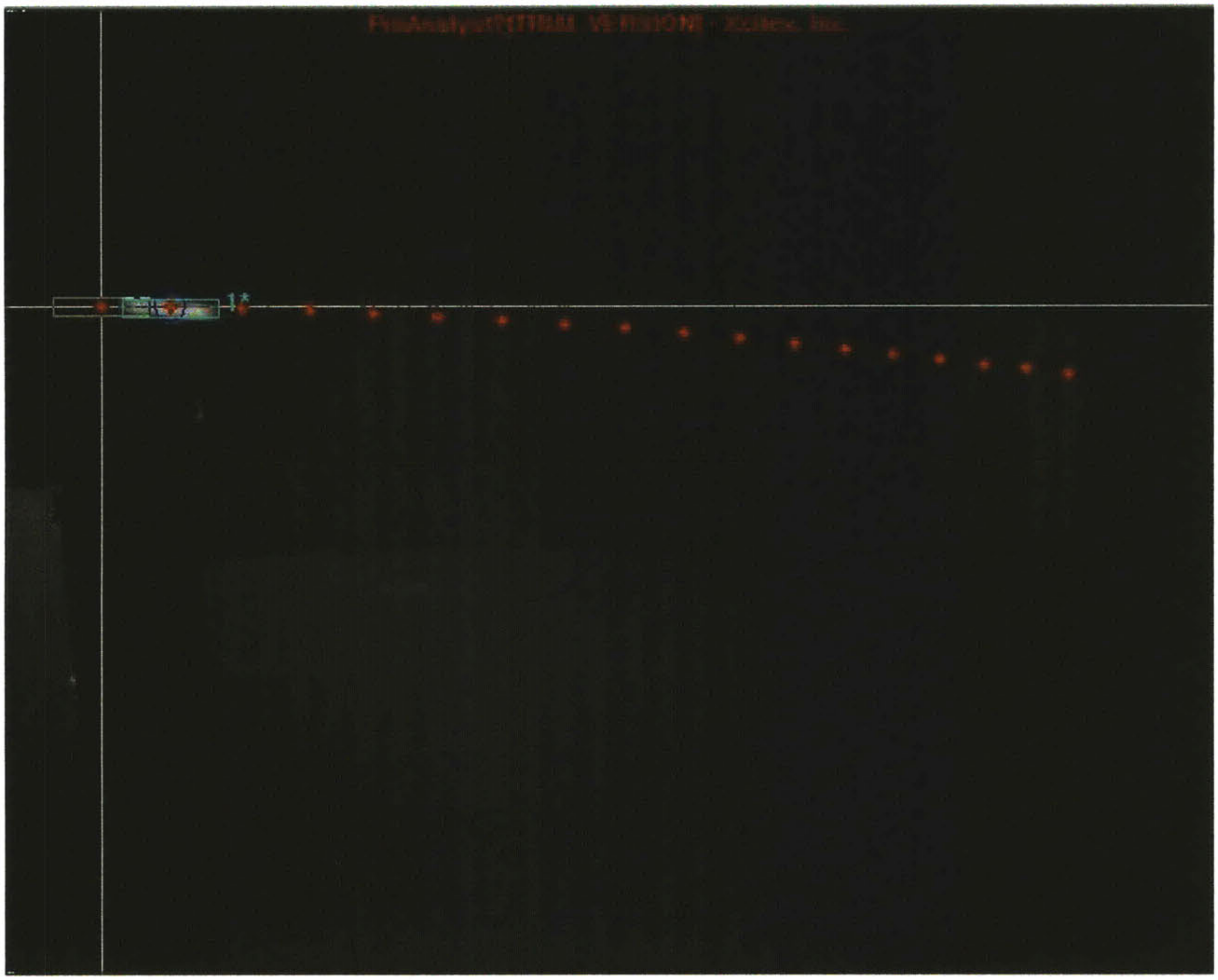
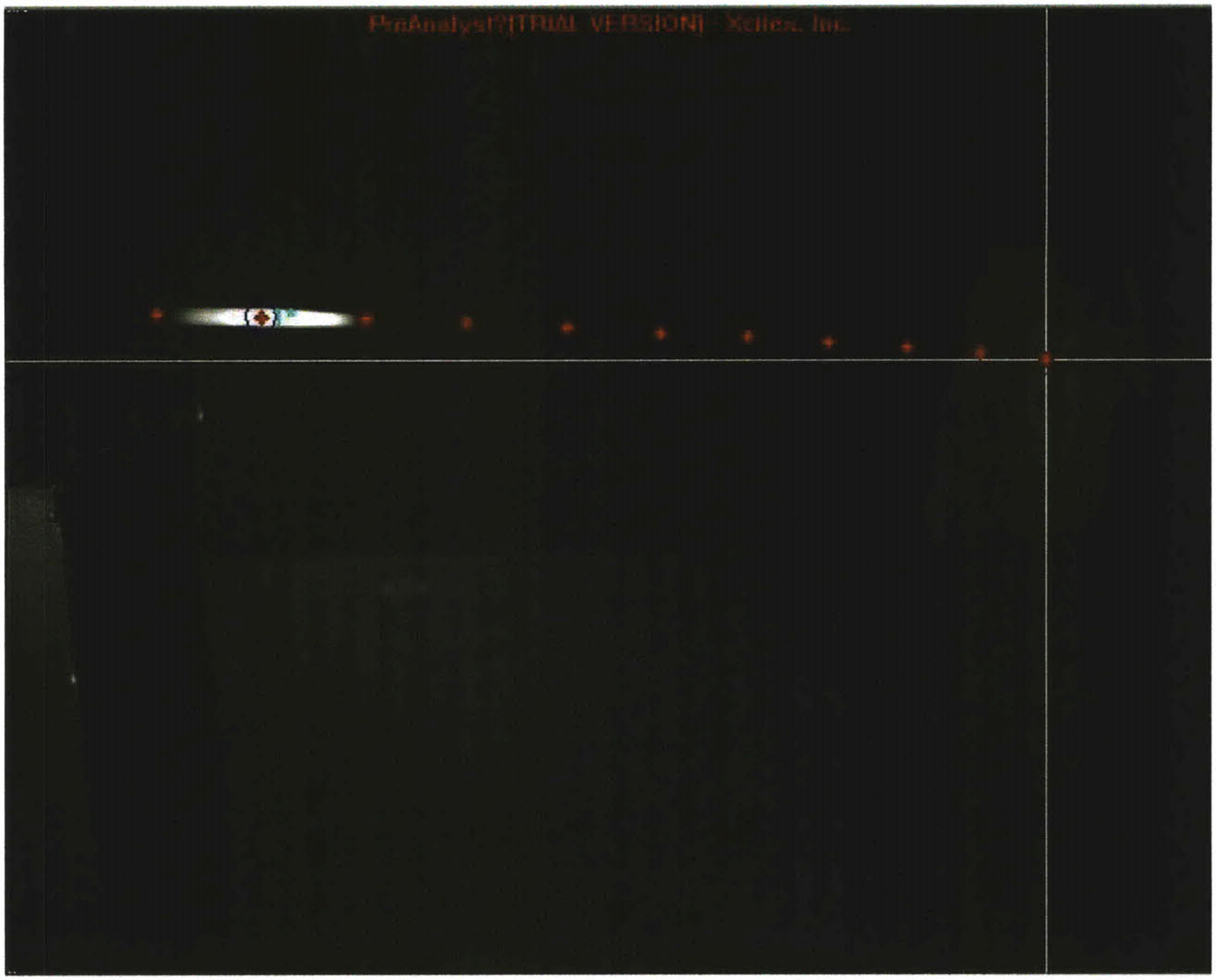


Trajectory of Model #6



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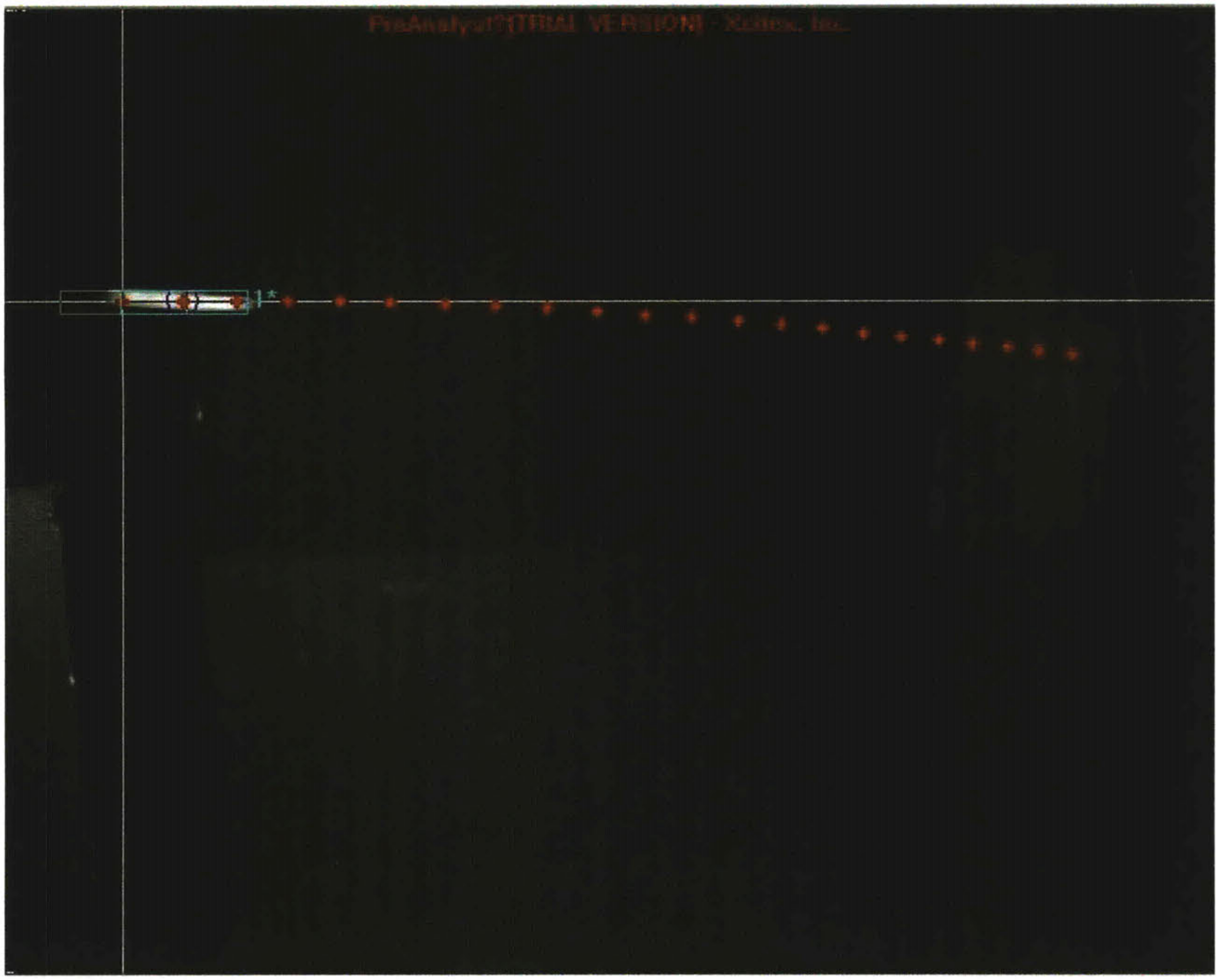

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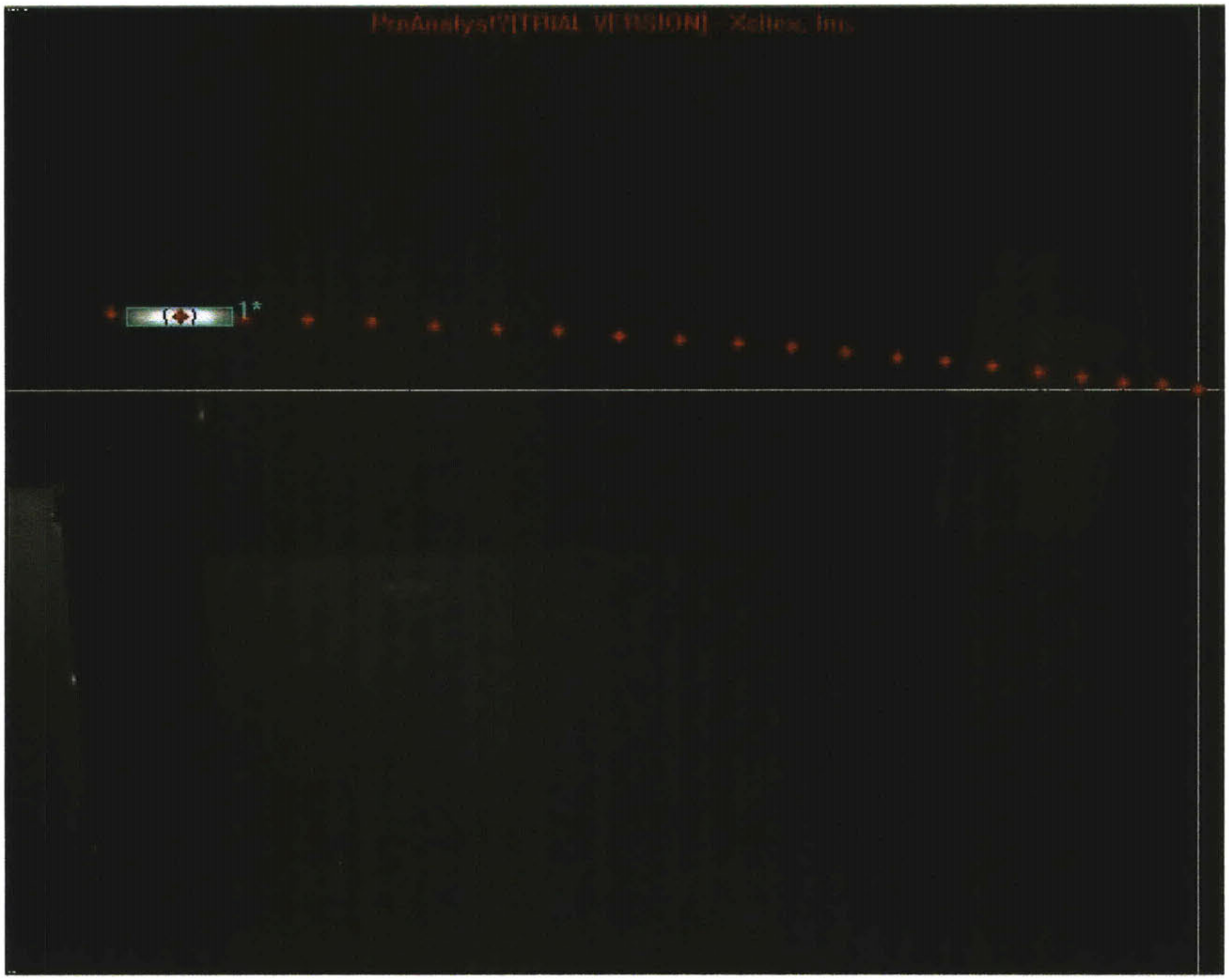

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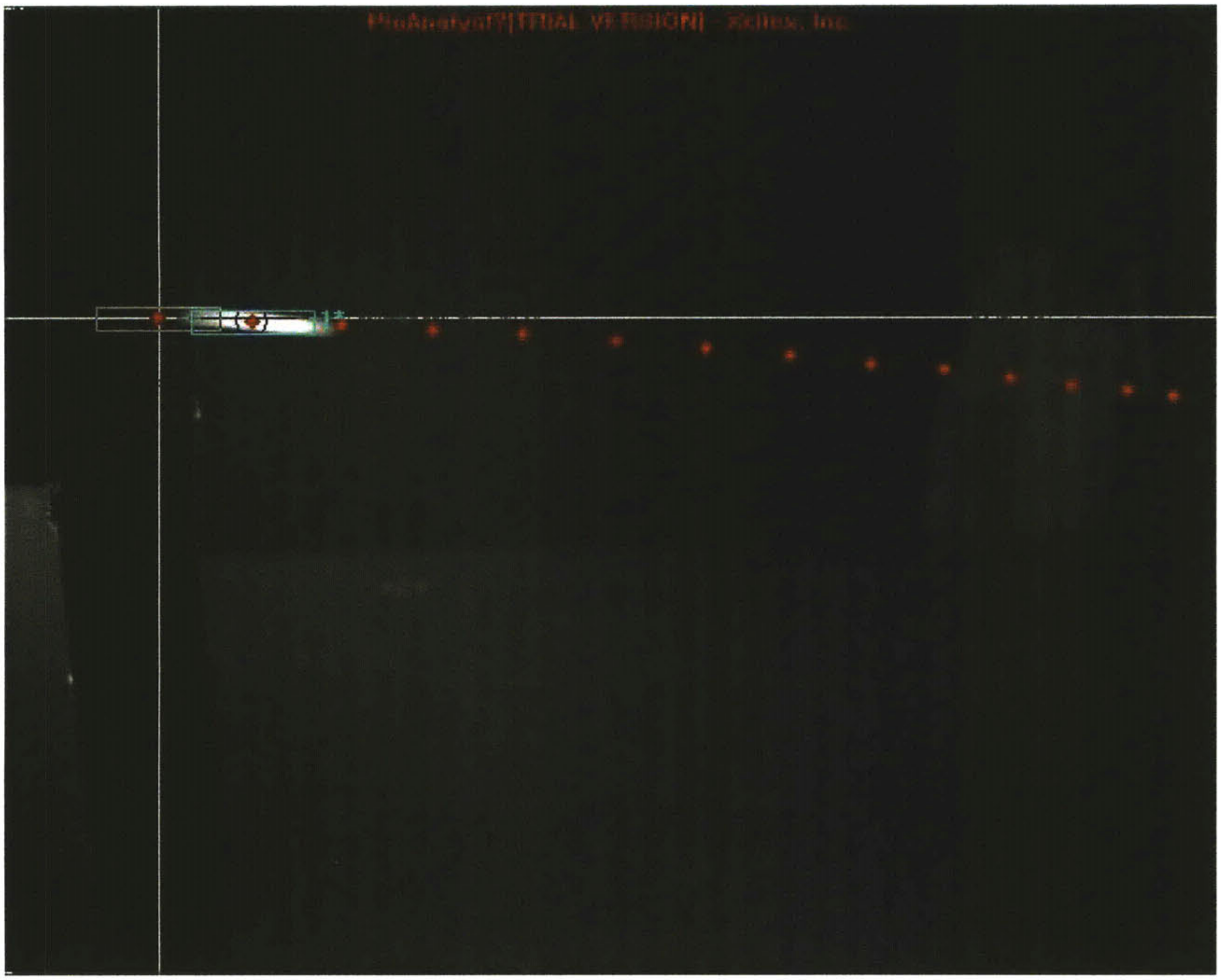
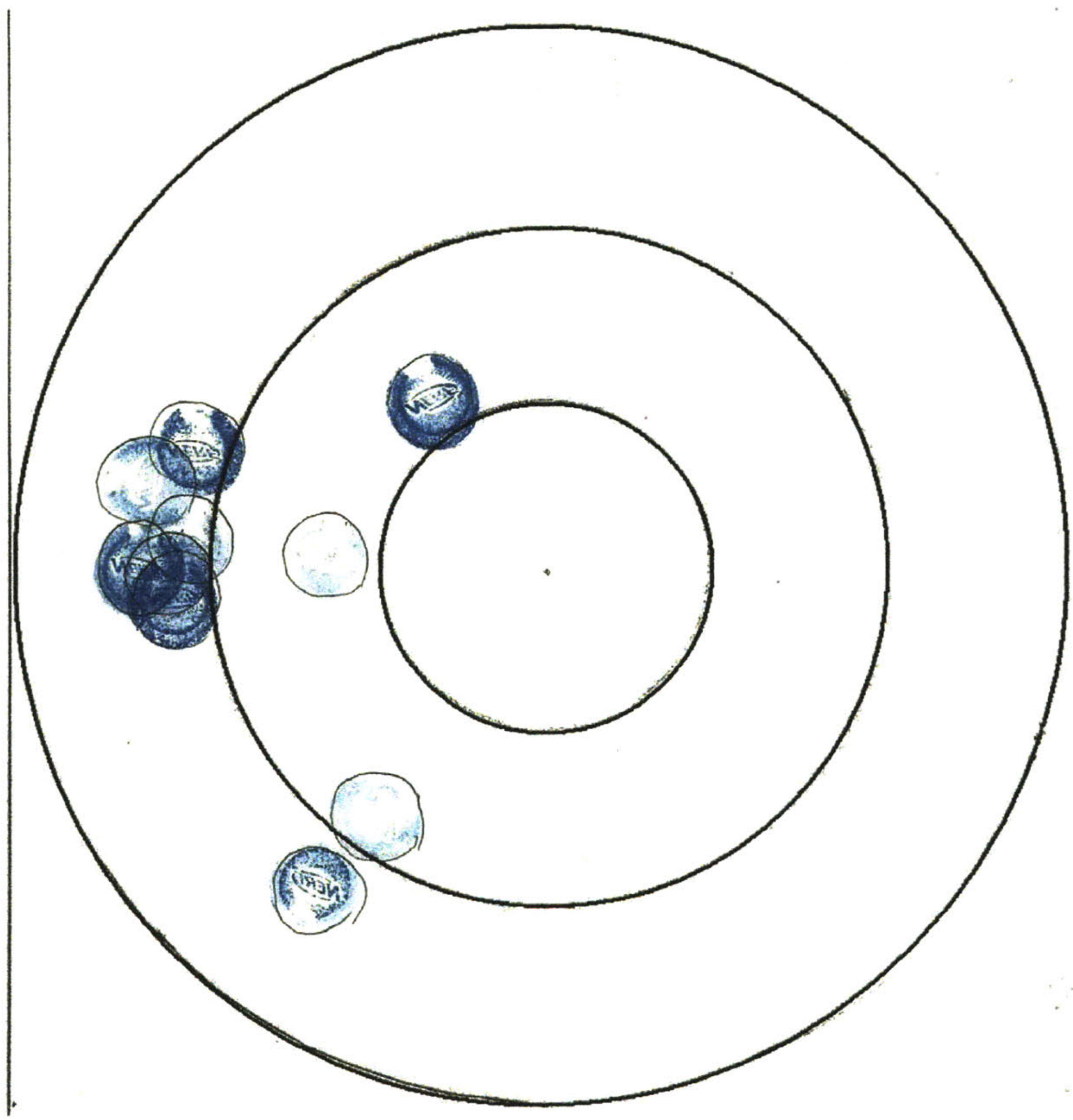


Trajectory of Model #10

Appendix B: Image

B-3 Scatter of Accuracy Test

1



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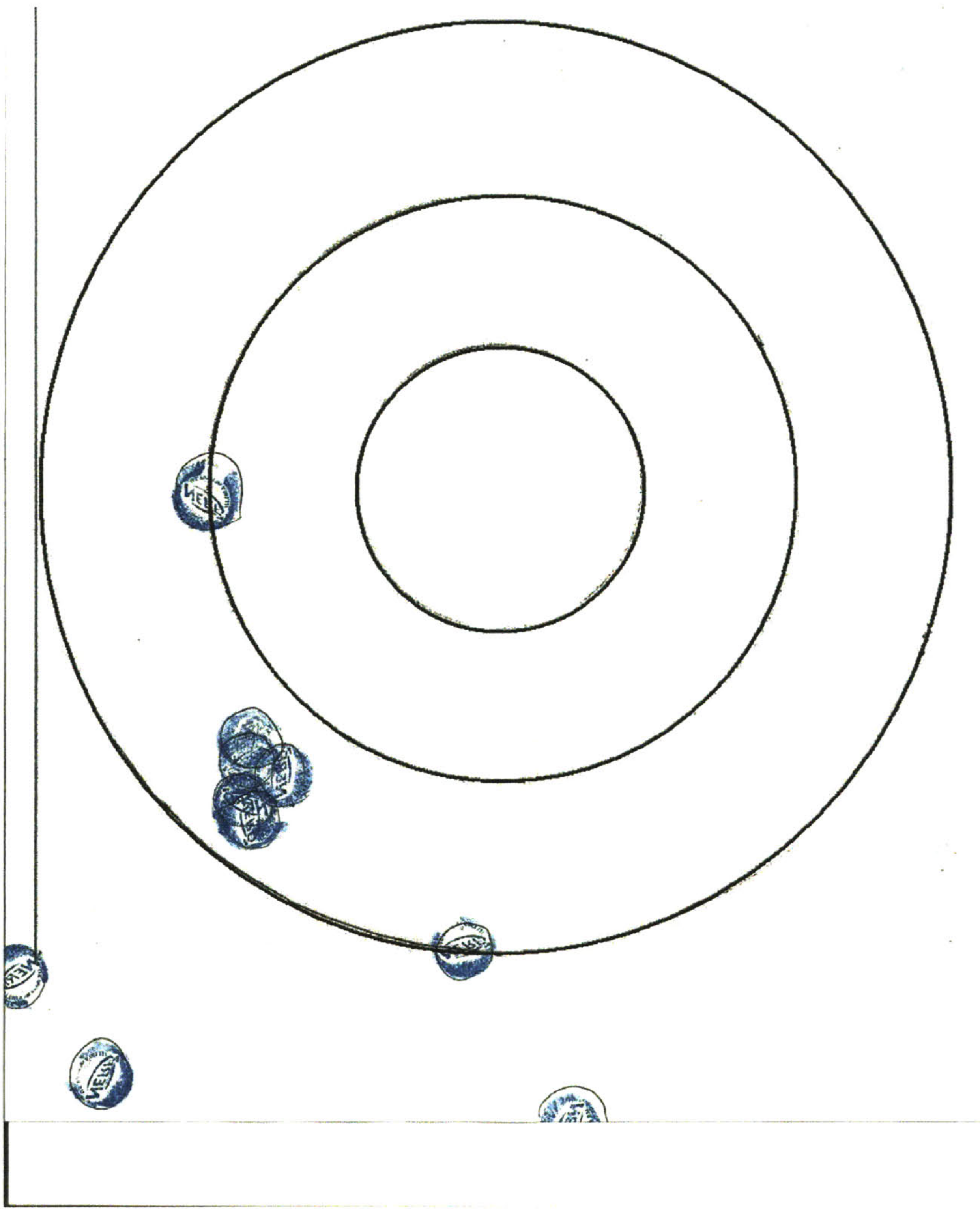

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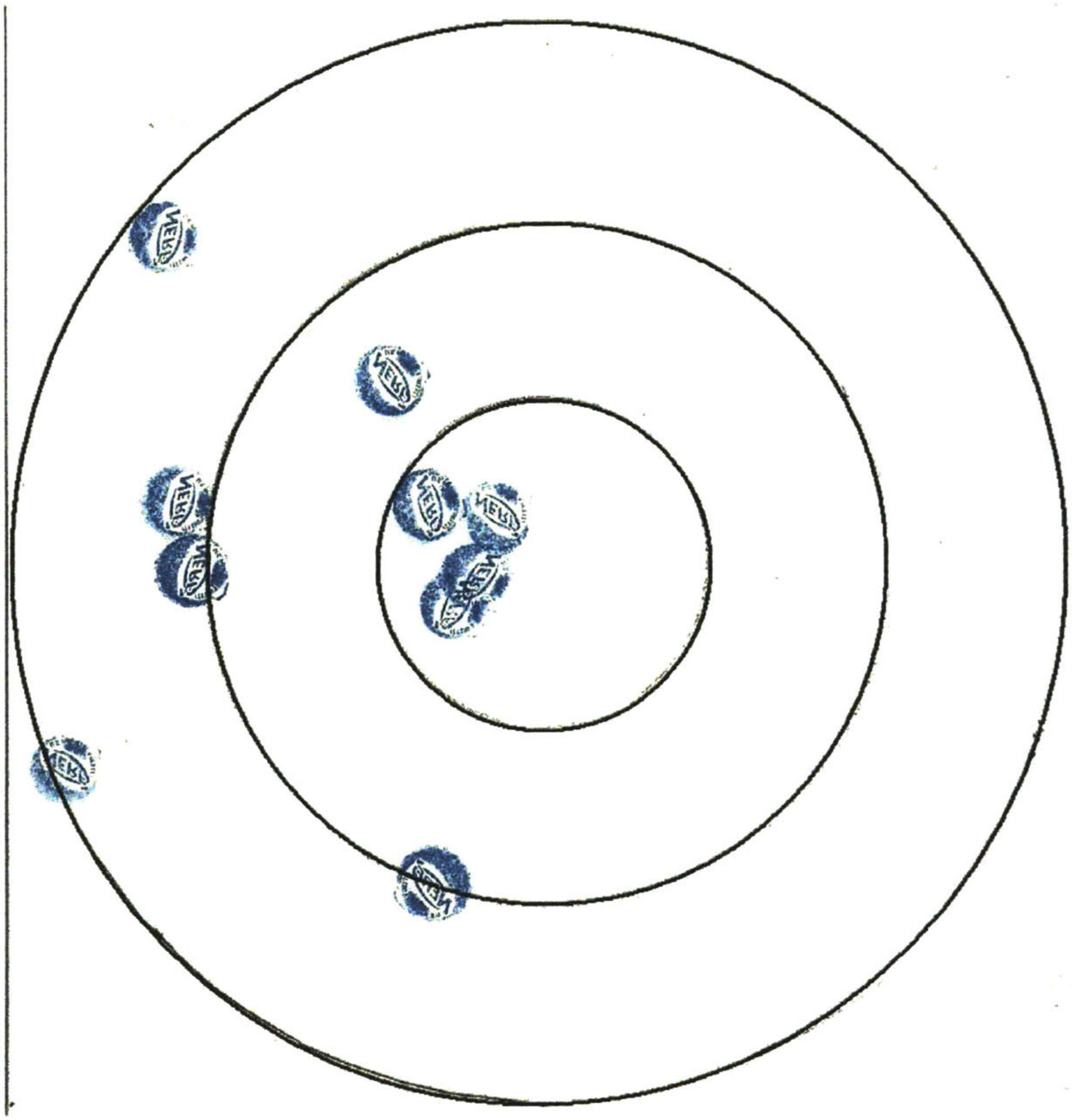

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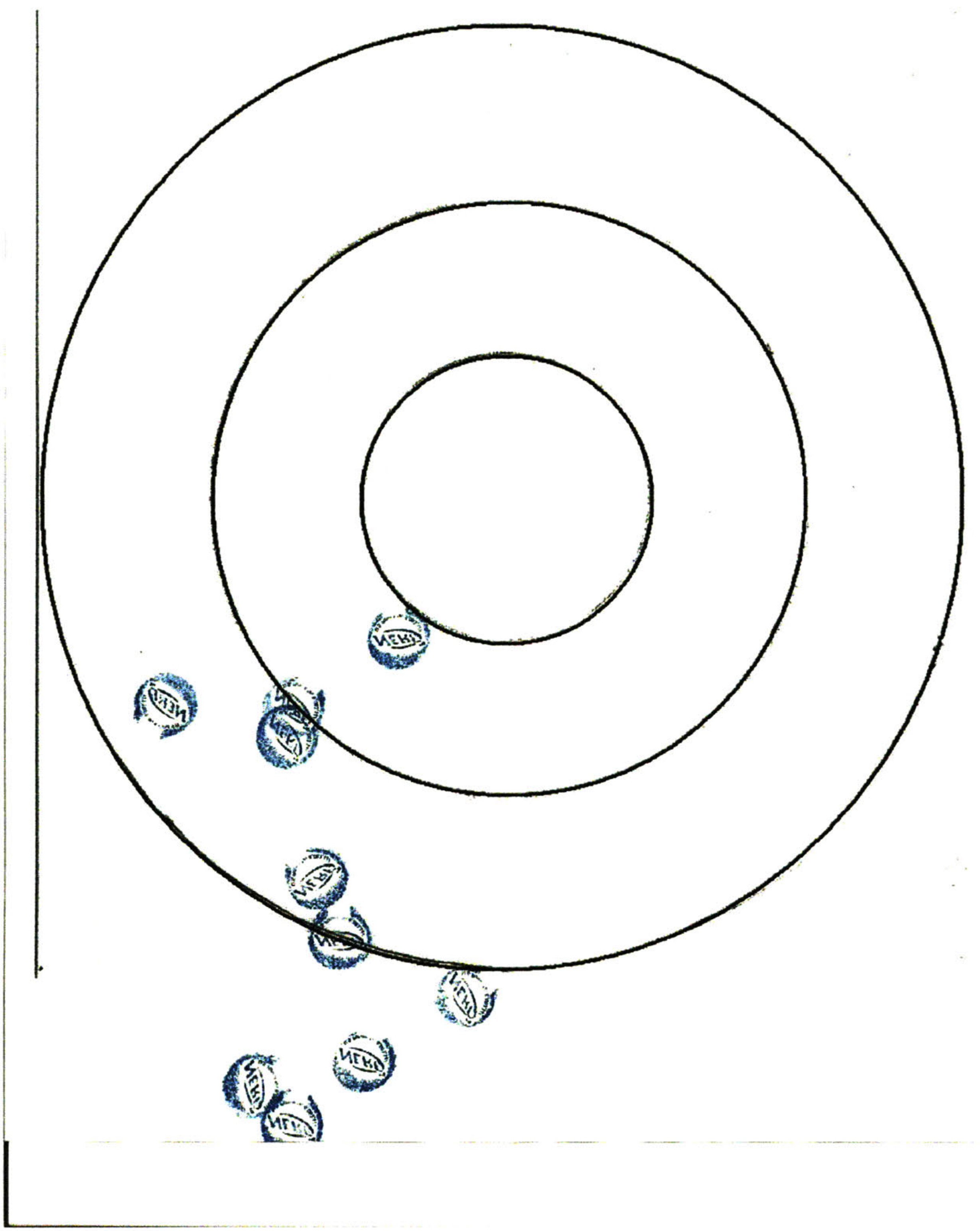

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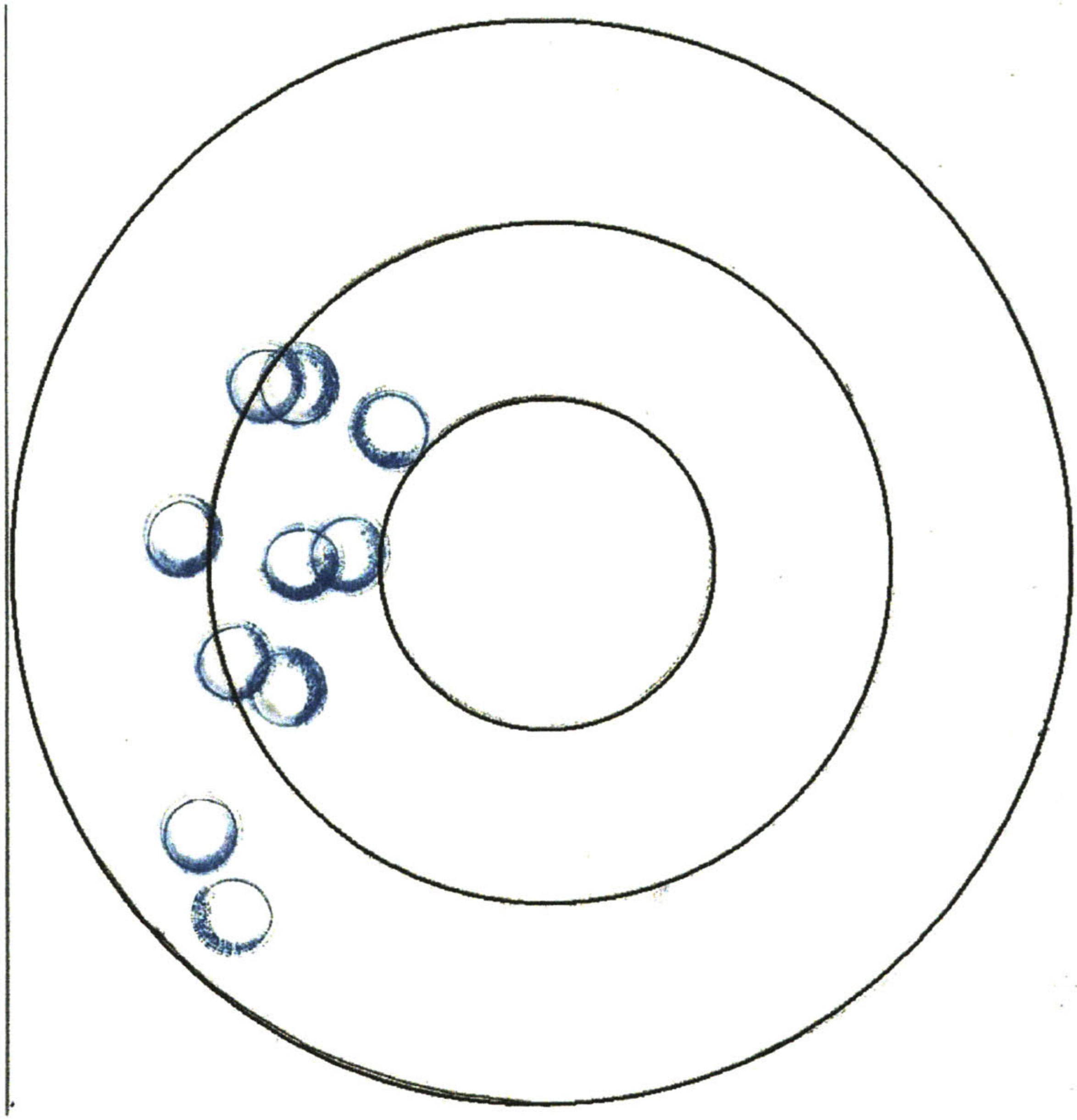

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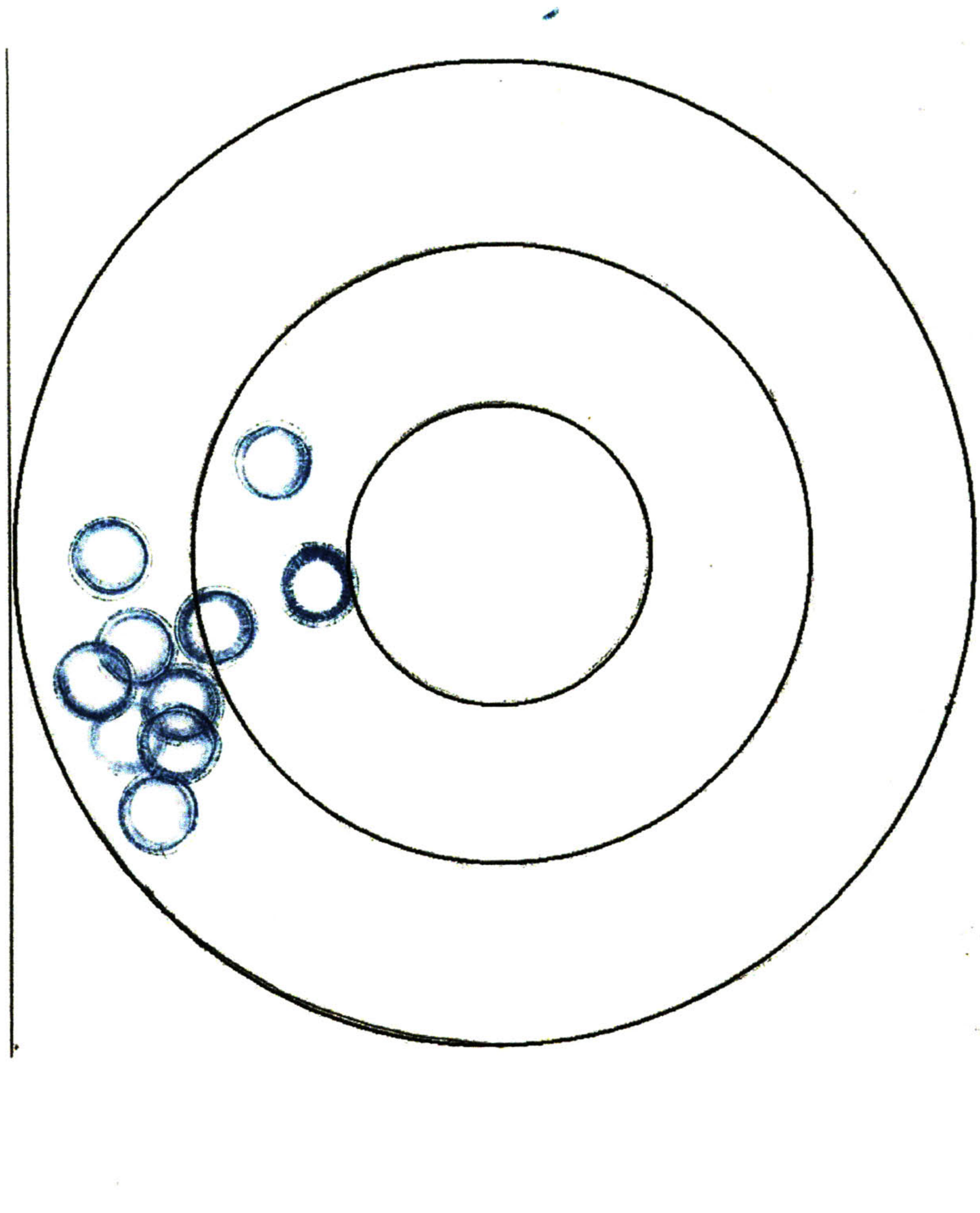

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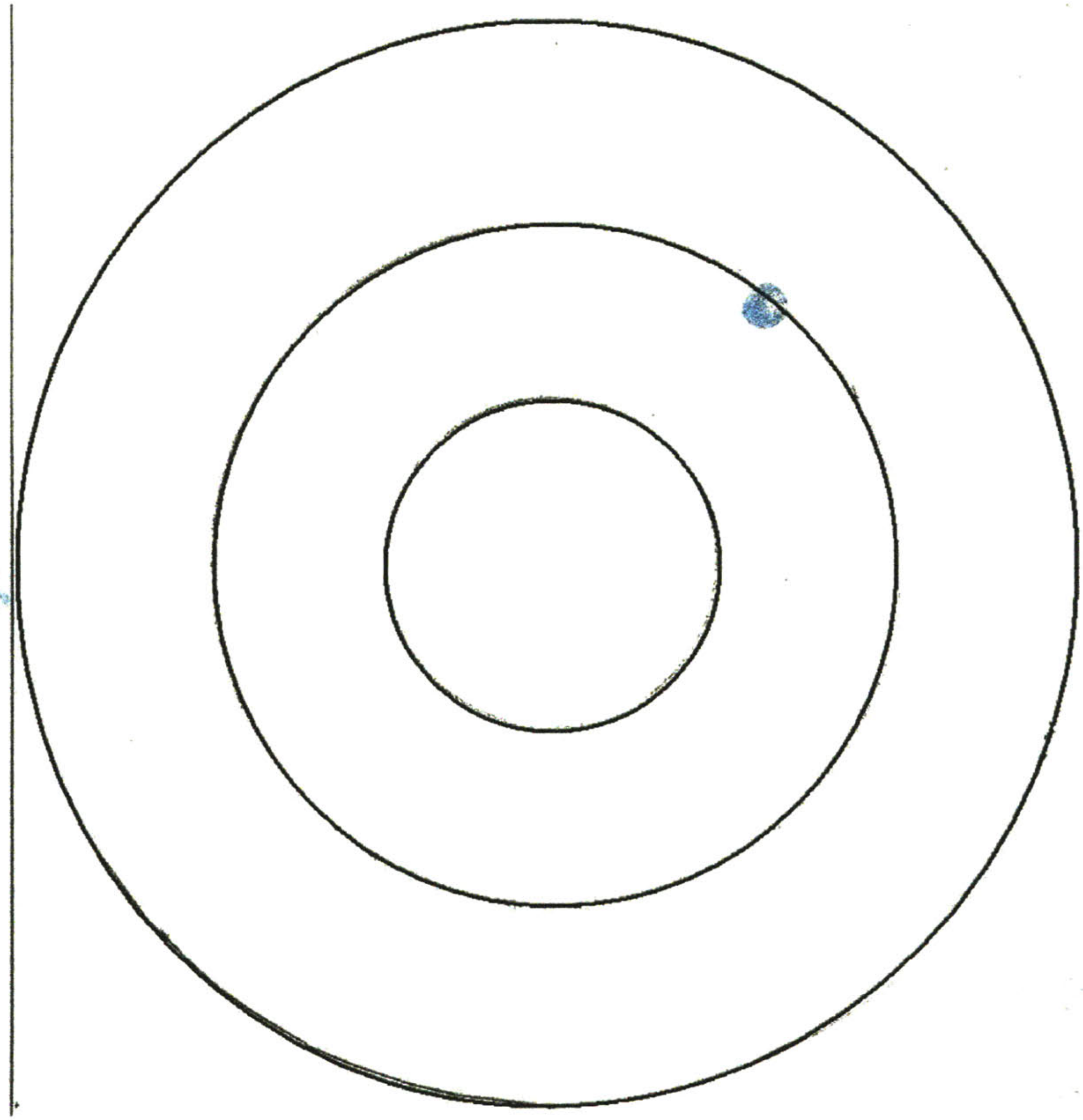

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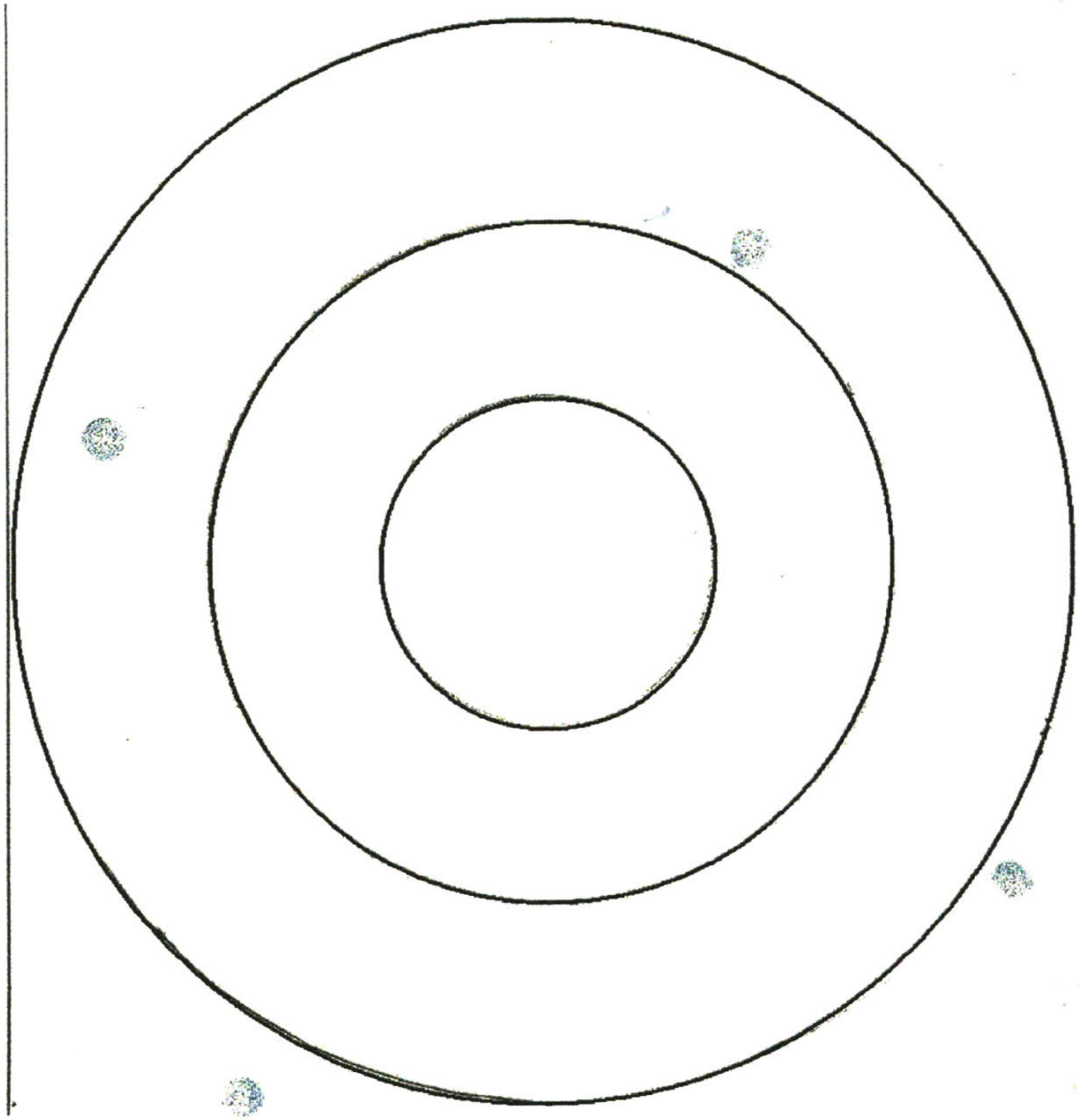

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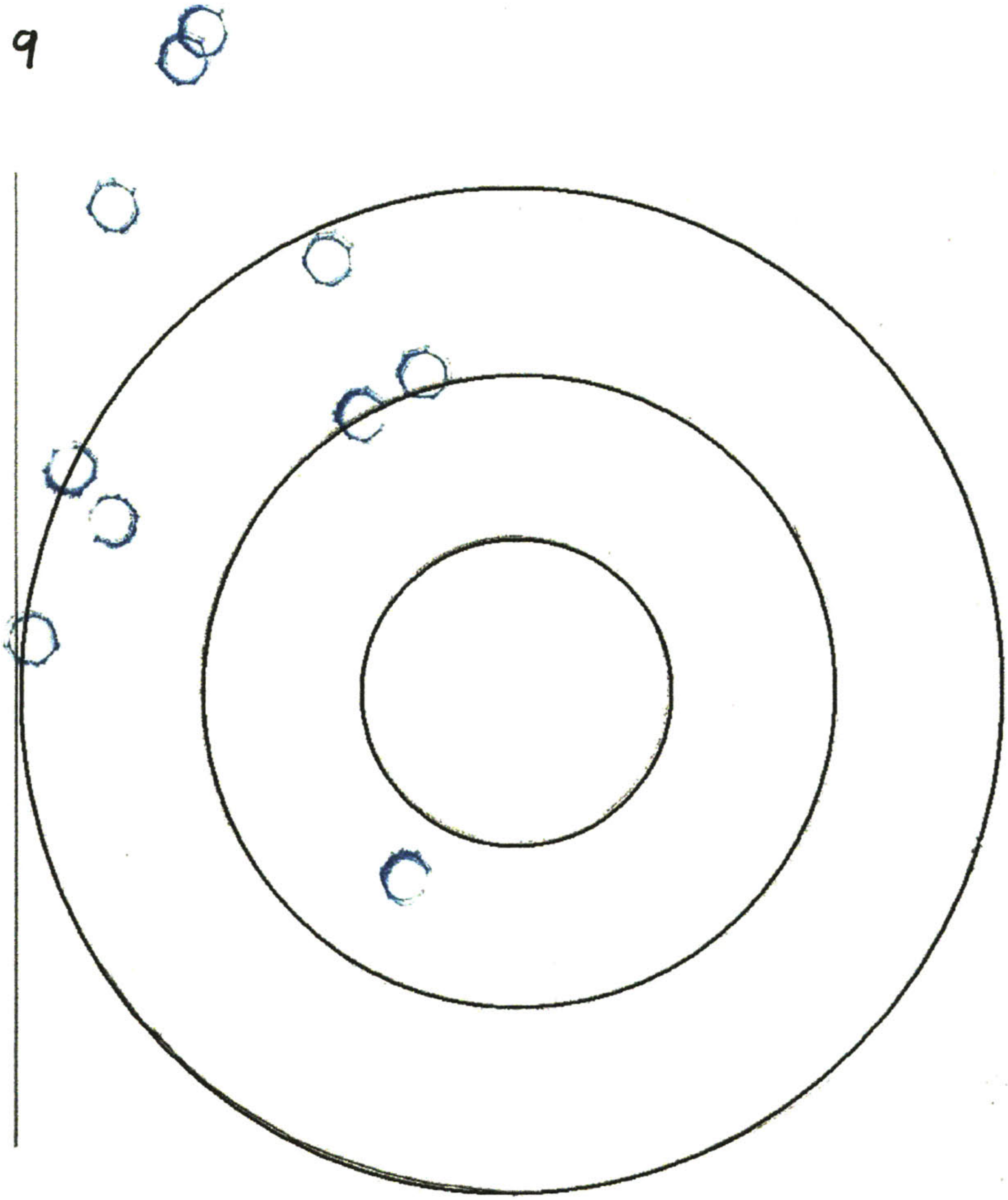

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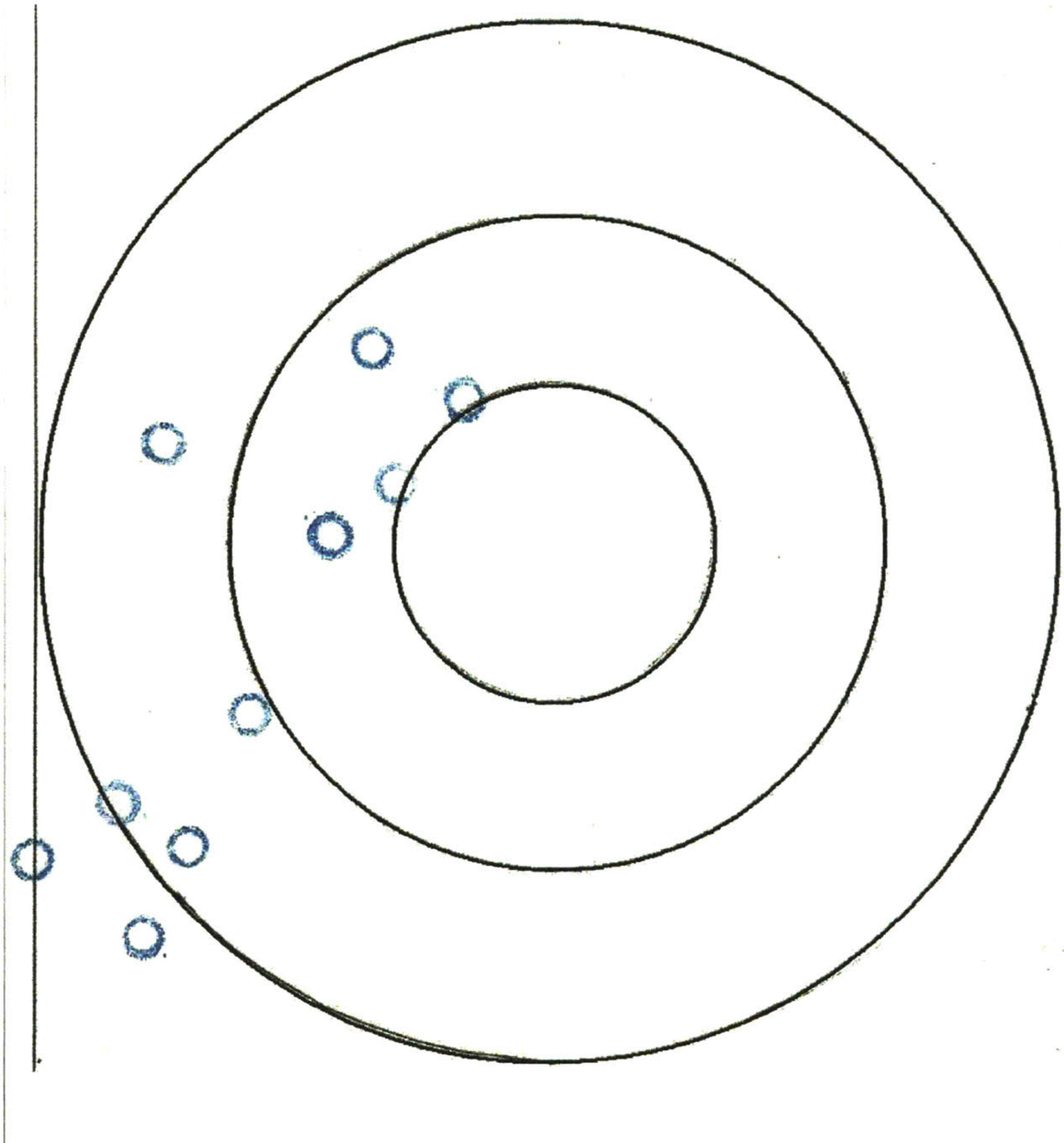
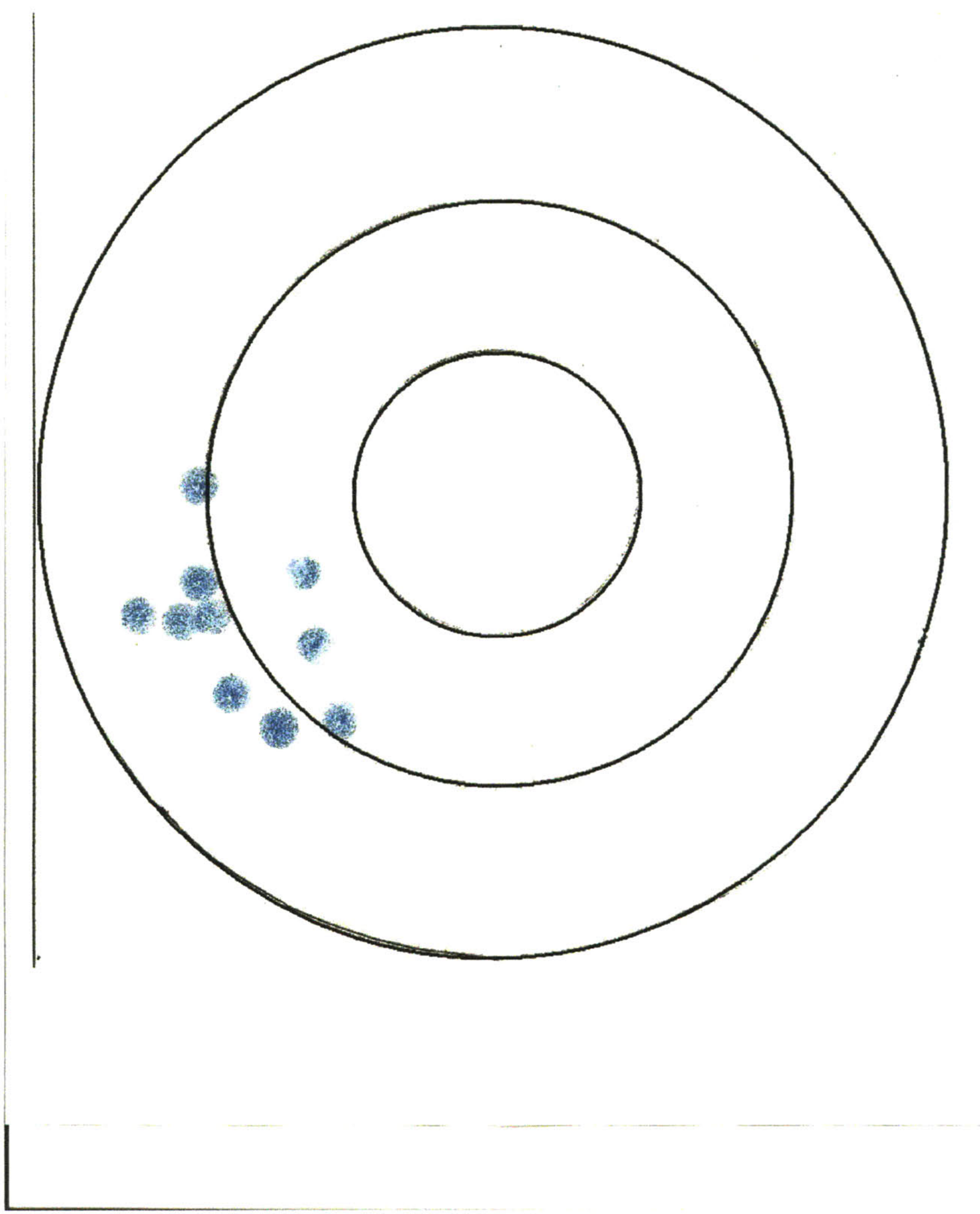


13-1



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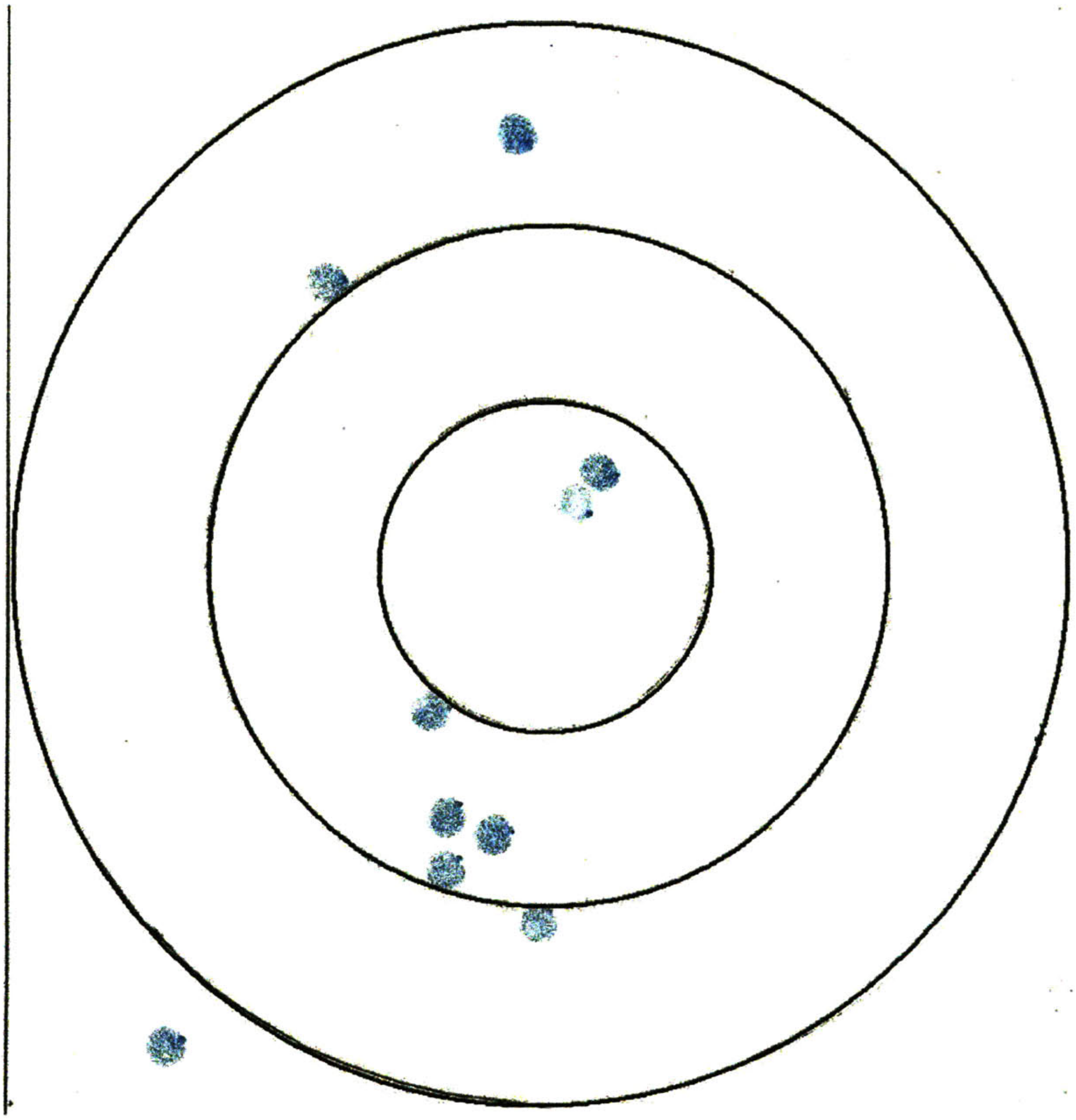

Appendix C: Data

C-1 Dimension of Projectile Models

	Height (m)	Radius (m)	Reference Area (m^2)*
1	0.073	0.00700	0.000153938
2	0.073	0.00700	0.000153938
3	0.073	0.00700	0.000153938
4	0.073	0.00700	0.000153938
5	0.071	0.00700	0.000153938
6	0.069	0.00705	0.000156145
7	0.090	0.00600	0.000113097
8	0.088	0.00600	0.000113097
9	0.068	0.00700	0.000153938
10	0.073	0.00600	0.000113097

	height (m)	radius (m)	Reference Area (m^2)*
13-1	0.088	0.00625	0.000122718
13-3	0.091	0.00625	0.000122718

*The reference area means the area of projectile model which is shown in front of the direction of flying.

Appendix C: Data

C-2 Distance

	Distance of Flight (m)*										AVG	MIN	MAX
1	10.10	10.50	8.50	9.00	10.00	10.40	8.60	9.00	9.20	9.10	9.44	8.50	10.50
2	7.80	7.60	8.00	7.70	7.30	7.50	7.90	7.70	7.00	7.30	7.58	7.00	8.00
3	8.20	9.20	9.80	8.00	8.00	8.40	9.20	9.70	8.10	8.20	8.68	8.00	9.80
4	4.10	5.10	5.00	5.50	5.50	4.00	5.10	5.00	5.60	5.50	5.04	4.00	5.60
5	8.50	10.00	9.10	9.20	9.30	8.50	9.70	9.10	9.20	9.40	9.20	8.50	10.00
6	7.00	7.50	7.20	7.80	8.30	7.10	7.40	7.00	8.00	8.30	7.56	7.00	8.30
7	13.50	11.50	10.90	12.30	13.00	13.50	11.50	10.90	12.00	13.30	12.24	10.90	13.50
8	6.00	5.20	6.80	5.00	6.30	5.80	5.20	6.80	5.00	6.10	5.82	5.00	6.80
9	7.50	8.10	7.70	7.20	9.00	7.30	8.20	7.60	7.00	9.00	7.86	7.00	9.00
10	12.50	12.00	11.50	13.90	11.80	12.50	12.00	11.50	14.00	11.70	12.34	11.50	14.00

	Distance of Flight (m)*										AVG	MIN	MAX
13-1	9.10	8.90	9.00	9.50	10.20	9.30	8.90	8.90	9.50	10.10	9.34	8.90	10.20
13-3	13.00	12.20	12.10	12.70	12.20	12.80	12.40	12.50	12.30	12.20	12.44	12.10	13.00

*The longest and shortest distances are removed.

Appendix C: Data

C-3 Velocity

Initial Velocity

	Initial Velocity (m/sec)					AVG (m/sec)	MIN (m/sec)	MAX (m/sec)
1	19.7109	19.5037	19.6030	19.5819	19.9960	19.6791	19.5037	19.9960
2	14.1029	14.4680	14.1029	14.6187	14.3296	14.3244	14.1029	14.6187
3	15.8481	16.7049	16.1774	16.2500	16.3636	16.2688	15.8481	16.7049
4	10.3726	10.3726	10.9161	10.8826	9.6484	10.4385	9.6484	10.9161
5	18.6761	17.9552	17.8379	18.0173	17.9510	18.0875	17.8379	18.6761
6	15.4580	13.9102	15.3411	15.0440	15.5475	15.0601	13.9102	15.5475
7	21.7389	22.8960	22.3562	23.5416	23.1569	22.7379	21.7389	23.5416
8	12.6052	12.2228	12.9791	12.9720	13.2604	12.8079	12.2228	13.2604
9	14.8765	15.0128	13.8717	14.2778	12.3971	14.0872	12.3971	15.0128
10	21.7820	20.7351	21.2290	22.2282	22.6715	21.7291	20.7351	22.6715

	Initial Velocity (m/sec)					AVG (m/sec)	MIN (m/sec)	MAX (m/sec)
13-1	16.5947	15.3647	16.1447	16.1695	15.9000	16.0347	15.3647	16.5947
13-3	18.5313	18.5313	18.5313	18.8911	18.1714	18.5313	18.1714	18.8911

Average Velocity

	Average Velocity (m/sec)					AVG (m/sec)	MIN (m/sec)	MAX (m/sec)
1	14.0000	13.7450	13.7500	13.9500	14.3060	13.9502	13.7450	14.3060
2	11.5000	11.2500	11.4500	11.3000	11.3500	11.3700	11.2500	11.5000
3	12.5000	12.5500	12.3500	12.5000	12.9000	12.5600	12.3500	12.9000
4	9.2000	9.0500	9.4500	9.0250	8.5000	9.0450	8.5000	9.4500
5	13.5000	13.8500	13.5500	13.7000	13.7400	13.6680	13.5000	13.8500
6	12.1000	11.5500	12.5000	12.1500	12.7500	12.2100	11.5500	12.7500
7	15.5000	13.0000	14.0000	15.0000	13.7500	14.2500	13.0000	15.5000
8	10.0000	10.5000	11.1500	10.0000	10.7000	10.4700	10.0000	11.1500
9	12.5000	12.4500	12.5500	11.5500	10.7500	11.9600	10.7500	12.5500
10	14.0000	15.5000	15.8500	16.4500	16.5000	15.6600	14.0000	16.5000

	Average Velocity (m/sec)					AVG (m/sec)	MIN (m/sec)	MAX (m/sec)
13-1	9.9568	9.2803	9.4608	10.0251	10.4940	10.2622	9.2803	10.4940
13-3	11.1188	12.9719	11.4894	11.3724	10.1760	12.0453	10.1760	12.9719

Appendix C: Data

C-4 Kinetic Energy

	Mass (kg)	Initial Velocity (m/sec)	Average Velocity (m/sec)	Initial Kinetic Energy (J)	Average Kinetic Energy (J)
1	0.00134	19.679060	13.950200	0.259332	0.130319
2	0.00141	14.324390	11.370000	0.144812	0.091237
3	0.00158	16.268790	12.560000	0.209291	0.124744
4	0.00145	10.438450	9.045000	0.078899	0.059240
5	0.00135	18.087470	13.668000	0.220716	0.126034
6	0.00169	15.060120	12.210000	0.192196	0.126334
7	0.00070	22.737890	14.250000	0.180670	0.070960
8	0.00096	12.807860	10.470000	0.078330	0.052344
9	0.00158	14.087160	11.960000	0.156466	0.112781
10	0.00091	21.729120	15.660000	0.214122	0.111214

	Mass (kg)	Initial velocity (m/sec)	Average velocity (m/sec)	Initial Kinetic Energy (J)	Average Kinetic Energy (J)
13-1	0.00170	16.034746	10.262237	0.218546	0.089516
13-3	0.00130	18.531259	12.045318	0.223215	0.094308

Appendix C: Data

C-5 Drag Coefficient

Mass (kg)	a_d (m/s^2)	F_d (kg*m/s^2)	Air Density (kg/m^3)	v (m/sec)	A (m^2)	C_d
0.0013393	22.91544	0.030690649	1.204	19.67906	0.000153938	0.855174861
0.0014115	11.81756	0.016680486	1.204	14.32439	0.000153938	0.877231021
0.0015815	14.83516	0.023461806	1.204	16.26879	0.000153938	0.956551772
0.0014482	5.57380	0.008071977	1.204	10.43845	0.000153938	0.799402404
0.0013493	17.67788	0.023852763	1.204	18.08747	0.000153938	0.78675699
0.0016948	11.40048	0.019321534	1.204	15.06012	0.000156145	0.906275271
0.0006989	33.95156	0.023728745	1.204	22.73789	0.000113097	0.674101956
0.0009550	9.35144	0.008930625	1.204	12.80786	0.000113097	0.799613016
0.0015769	8.50864	0.013417274	1.204	14.08716	0.000153938	0.729583433
0.0009070	24.27648	0.022018767	1.204	21.72912	0.000113097	0.684951564

Appendix C: Data

C-6 Accuracy

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Variance (cm^2)
1	3.90	4.23	7.00	6.90	7.10	7.20	7.80	5.70	7.50	7.70	1.9936
2	6.20	7.70	8.10	7.60	8.80	8.90	10.10	15.00	15.40	13.70	11.0428
3	1.20	1.40	1.80	2.50	4.60	6.70	7.10	9.50	6.30	9.80	10.6943
4	3.60	6.20	6.90	8.60	9.10	10.00	11.00	12.40	13.70	14.10	11.4560
5	4.00	3.60	4.70	5.90	6.50	6.70	5.80	5.00	7.90	8.50	2.5449
6	5.20	3.70	5.90	7.70	7.60	7.10	7.60	8.50	8.70	8.70	2.7268
7	6.30	10.60	15.40	22.00	25.00	16.70	15.00	16.00	17.20	27.50	40.2334
8	7.20	8.70	11.50	10.50	16.90	20.40	21.00	20.00	23.30	18.00	33.2294
9	4.30	10.00	9.00	10.10	6.60	6.80	9.70	12.90	14.70	14.90	12.2000
10	3.40	3.20	4.30	5.20	7.90	6.60	9.80	9.10	10.10	11.80	9.2893

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Variance (cm^2)
13-1	4.40	6.00	5.00	6.40	6.70	6.60	7.30	8.20	7.20	6.90	1.2379
13-3	1.60	2.30	6.80	8.50	3.20	4.80	4.80	5.80	6.50	11.40	8.6957

Appendix C: Data

C-7 Tip Factor

	D^{*1} (cm)										Avg. D^{*1} (cm)	Avg. R^{*1} (m)	Avg. R^{*2} (m)	Avg. A^{*2}(m^2)
1	1.6	1.6	1.7	1.6	1.5	1.5	1.6	1.6	1.7	1.6	1.6000	0.0080	0.00960	0.0002895292
2	1.2	1.2	1.3	1.4	1.2	1.2	1.2	1.2			1.2375	0.0062	0.00743	0.0001731980
3	1.2	1.3	1.3	1.4	1.2	1.3	1.2	1.3	1.3	1.2	1.2700	0.0064	0.00762	0.0001824147
4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3000	0.0065	0.00780	0.0001911345
5	1.3	1.4	1.4	1.5	1.4	1.5	1.4	1.4	1.4	1.4	1.4100	0.0071	0.00846	0.0002248488
6	1.5	1.6	1.6	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.5800	0.0079	0.00948	0.0002823362
7	0.8	0.9									0.8500	0.0043	0.00510	0.0000817128
8	0.8	0.8	0.8	0.9							0.8250	0.0041	0.00495	0.0000769769
9	1	1	1	1	1.1	0.9	1	1	1	1	1.0000	0.0050	0.00600	0.0001130973
10	0.8	0.9	0.8	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.8300	0.0042	0.00498	0.0000779128

	D^{*1} (cm)										Avg. D^{*1} (cm)	Avg. R^{*1} (m)	Avg. R^{*2} (m)	Avg. A^{*2}(m^2)
13-1	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.8200	0.0041	0.00492	0.0000760466
13-3	0.7	0.7	0.8	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7300	0.0037	0.00438	0.0000602696

D^{*1}: the diameter of mark which is produced when flying projectile bumps to the wall at 2m distance

R^{*1}: the radius of mark which is produced when flying projectile bumps to the wall at 2m distance

R^{*2}: the radius of mark which is produced when flying projectile bumps to the wall at 1m distance

A^{*2}: the area of mark which is produced when flying projectile bumps to the wall at 1m distance

Appendix C: Data

C-8 Kinetic Energy Density

	Average Kinetic Energy (J)	Area (m^2)	Kinetic E Density (J/m^2)
1	0.1303193008	2.895291790E-04	450.107658
2	0.0912371722	1.731979665E-04	526.779696
3	0.1247436592	1.824146925E-04	683.846556
4	0.0592400873	1.911344970E-04	309.939274
5	0.1260342162	2.248488128E-04	560.528716
6	0.1263338663	2.823361884E-04	447.458992
7	0.0709601906	8.171282492E-05	868.409466
8	0.0523439798	7.697687399E-05	679.996173
9	0.1127811495	1.130973355E-04	997.204302
10	0.1112143446	7.791275445E-05	1427.421549

	Average Kinetic Energy (J)	Area (m^2)	Kinetic E Density (J/m^2)
13-1	0.0895164870	7.604664841E-05	1177.126000
13-3	0.0943082996	6.026957010E-05	1564.774718

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